BBC

STEPHEN HAWKING
WHAT HE TAUGHT US, AS TOLD BY HIS STUDENTS, PEERS AND RIVALS

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How freezing patients saves lives

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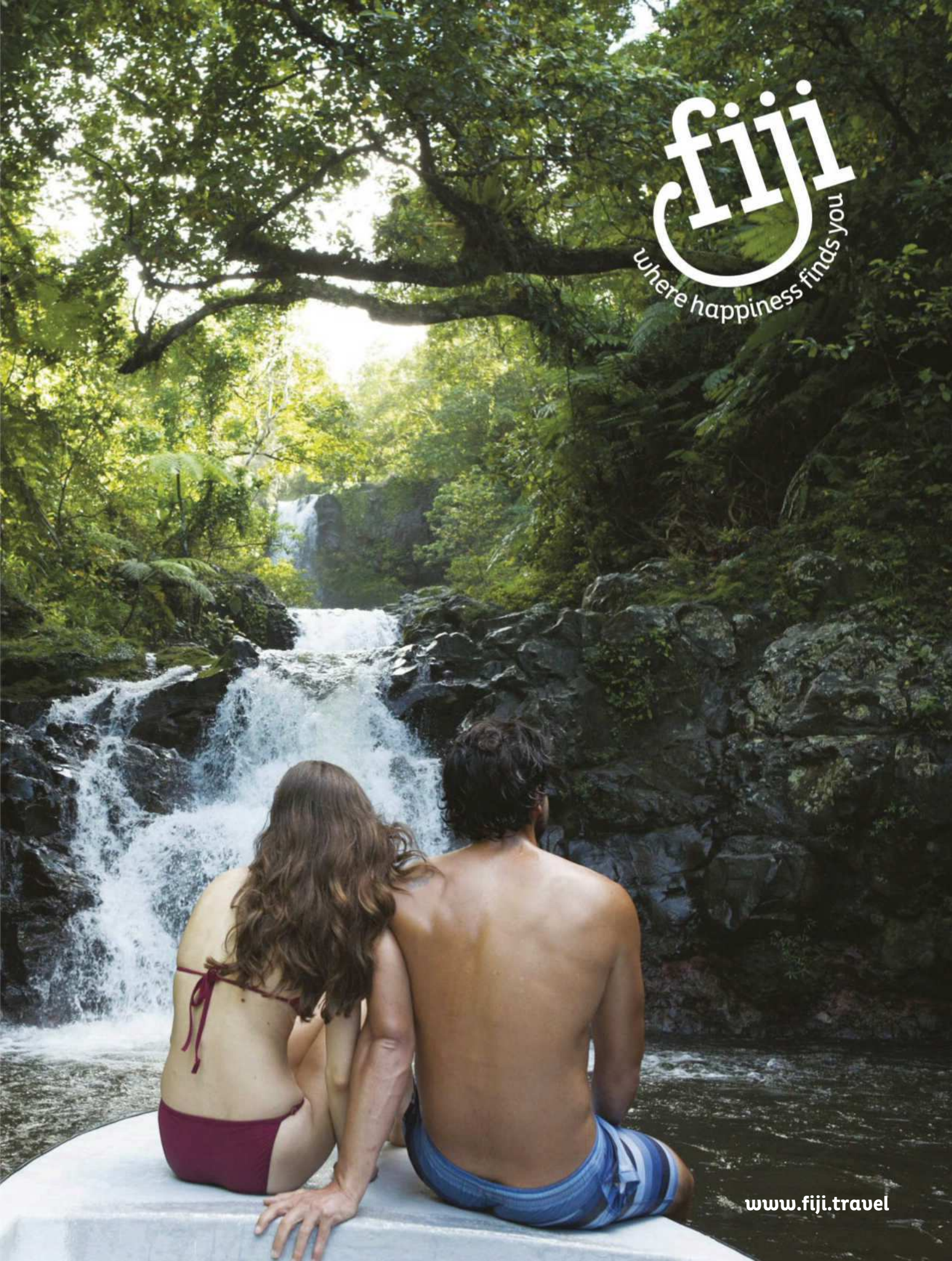
The battle for dominance over our climate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Robots can be **biased** → p56

WELCOME

The world has lost a giant. Prof Stephen Hawking, the Galaxy's best-known scientist and most unlikely cultural icon, died on Wednesday 14 March at his home in Cambridge. I've spent the days since speaking to those who knew Hawking and one clear theme emerges. Hawking was a stubborn man. Of course, he was funny and smart, that was clear for the world to see. But perhaps, to those of us watching from afar, his radiance hid the vital ingredient to his genius: true grit.

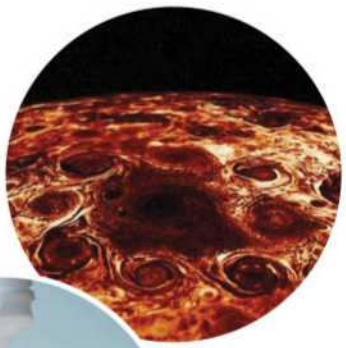
Hawking was determined to never let his condition slow him down. Sometimes literally: Hawking broke his leg on his 60th birthday after driving too fast off a kerb. He travelled the world, and even had a taste of zero-gravity. He hoped one day to get a trip on Richard Branson's Virgin Galactic.

But as the number of words he could communicate per minute dwindled, his jokes never did. It was this same resolve that would drive him, sometimes to the exacerbation of his colleagues, to spend years writing and rewriting his books so that he could share the elegance of the Universe with others. And ultimately it was this sheer strength of will, rather than a single eureka moment, that would propel him through the maths that underlined his work. Funnily enough, Hawking shared this personality trait with the most famous scientist of the last century, Einstein, who wrote of himself: "If I have a gift, it is that I am as stubborn as a mule". So if you learn anything from Hawking, I suggest that it isn't the nature of black holes or the origins of singularities, but that sometimes a little stubbornness can be a useful thing.

Daniel Bennett

Daniel Bennett, Editor

WHAT WE'VE FOUND OUT THIS MONTH



Jupiter's north pole contains **nine cyclones** → p14

Eyedrops with nanotech inside could help me **ditch my glasses** → p32

The **nuclear testing site** at Bikini Atoll is flourishing with **marine life** → p50

Cold helped a man recover from being technically **dead for five hours** → p64

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HAYLEY BENNETT
Real-life Robocops are here, but should we be worried about them? Science writer Hayley gives us the full lowdown on these computerised cops. → p56

CLIVE HAMILTON
As nations look to geoengineering as a possible way out of climate change, ethicist Clive warns that it could lead to a new kind of war. → p70

ALLA KATSNELSON
Alla has been reporting on health and science for over a decade. This issue, she finds out how wildlife could recover in the aftermath of a nuclear event. → p50

COVER: ANDY POTTS

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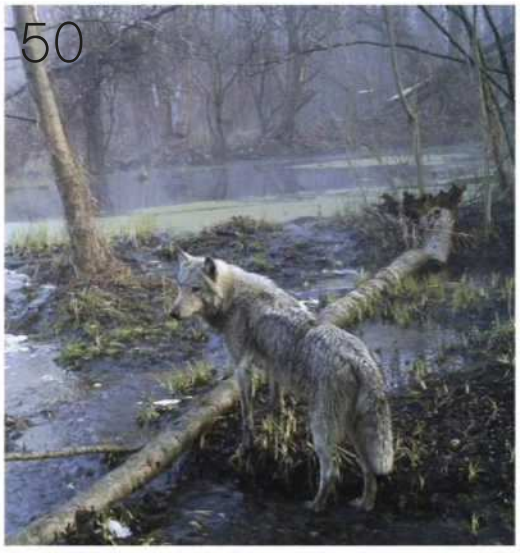

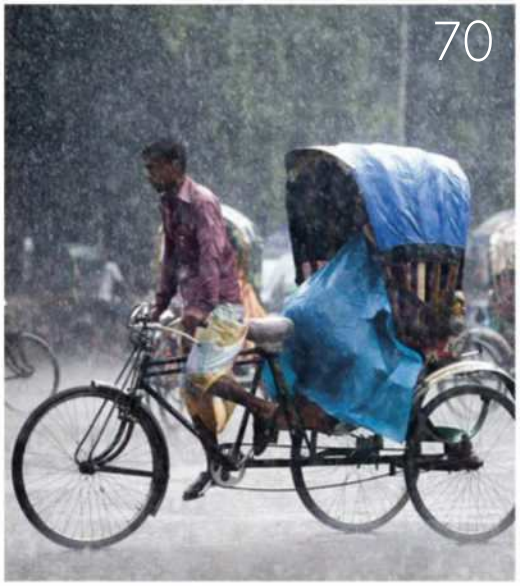

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Odd couple

JANAO BAY, BATANGAS,
PHILIPPINES

This juvenile trevally may seem to be in a spot of bother, but the reality isn't so bad. Young fish often seek protection from predators by hiding among the stinging tentacles of jellyfish, and this one seems to have taken that relationship a little too far.

"They don't seem to be affected by the stings," explains marine biologist Dr Helen Scales. "They just hide out until they can look after themselves a bit better. I think this little guy just got stuck."

It's likely that the fish managed to free itself after the photo was taken, and although the trevally probably escaped unharmed, the jellyfish may have suffered some damage.

Not to worry though, says Scales. "Jellyfish are very good at repairing themselves. If they lose a tentacle, for example, they can actually rearrange the others to maintain their symmetry. They have a remarkable ability to cope with damage."

PHOTO: SCOTT TUASON / UNDERWATER PHOTOGRAPHER OF THE YEAR 2018

REPLY

Your opinions on science, technology and *BBC Focus*

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Bolivia's Salar de Uyuni salt flats are home to the world's largest lithium deposits – but it's still not enough, argues Dr Adrian Todd

MESSAGE OF THE MONTH

A chemical reaction

While electric vehicles are a good idea in principle, they still require the generation of electricity. This is often achieved by the burning of fossil fuels, notably natural gas. This is more efficient in terms of carbon dioxide production and removes pollution from our cities.

However, electric cars require lithium batteries, and there simply is not enough lithium on Earth for every petrol vehicle to be replaced by an electric one. Obviously, new sources of lithium, more efficient batteries and new battery technology will probably come along.

I would like to suggest that, since every vehicle is already powered by an internal combustion engine, what we really need is an alternative liquid fuel to petroleum products. Methanol is the most likely candidate and some good work is being done to produce it photosynthetically from carbon dioxide and water.

Since the distribution systems for a liquid fuel are already in place, and as vehicles that utilise liquid fuel are already in widespread use, surely such research should be encouraged.

Sadly, responses to the problems caused by global warning are often too simplistic and are politically driven. The use of vegetable oils in diesel cars and diesel cars themselves being two recent examples.

Dr Adrian Todd, via email

Bear necessities

Last month I was fortunate enough to pick up an old copy of *BBC Focus* in my doctor's waiting room, and found it so interesting I asked the receptionist if I could take it home. I soon devoured the contents and promptly ordered a subscription to the magazine!

In the latest edition (March, p58), I noticed that the writer had some difficulty with knowing what to call a grizzly and polar bear hybrid – either 'grolar' and 'pizzly'. If the male is a grizzly then its offspring would be a grolar; if the male is a polar bear then the offspring would be a pizzly. This would be the same as a hybrid offspring from a tiger and a lion – tigon or liger depending on which species was the male. I hope this helps!

I would also like to take this opportunity to thank the person who donated their copy of the magazine to the surgery in Crumlin, Co Antrim, for introducing me to this wonderful publication.

Chris Stevenson, via email

On a lighter note...

I love your *Q&A* feature and was particularly interested in the question regarding whether plastic or paper currency is more hygienic (March, p90). It's some comfort, I suppose, to know that "harmful germs are less likely to stick to the plastic". But surely this is telling us something we know already – that even a germ can't live on a fiver nowadays?

Sorry, couldn't resist! Keep up the good work.

Ron Maslin, via email

Only the lonely

In your latest editor's letter (March, p3) you state: "We know that loneliness is deadly, but what we don't understand is how isolation affects us so fundamentally that it changes us at a molecular level." The answer to that is: stress!

PHOTOS: ALAMY, GREG MARTIN

Measure the underlying stress hormone levels of anyone with loneliness issues and you will almost certainly find consistently elevated levels of cortisol. Long-term stress has a dramatic effect on epigenetic expression of genes, as well as cellular ageing and its general resiliency.
Michael Lovren, via email

Smell you later

There has been a question on my mind about something I heard recently. Is it true that we can smell the presence of certain genes in other people, and if they smell like they have different genes to us we are attracted to them? I can't see how something like a gene can give off such a strong smell.
James Goodman, via email

Great question! The research you're talking about is commonly known as the sweaty T-shirt test. In the experiment, volunteers (who I bet ended up regretting it) were presented with a bunch of shirts that had been worn for two days, and were then asked to rate the owner's attractiveness based on the garment's smell alone. The shirts that people found most attractive tended to belong to people with the immunity genes most different from their own. How much this actually governs who we find attractive in the real world is, however, debatable.

As for how we can smell a gene – it's unclear. Animals seem to be able to manage similar feats: dogs, for instance, can be trained to sniff out cancer. So it's likely to be something that's common among mammals, but the exact mechanisms are unknown.
– Daniel Bennett, editor

Remembering the dead

Your article about the outsized mechanical puppet given the name Man Engine (March, p98) reminds me that the original 'man engine' was the name of the personnel transport system used down inside Cornish tin mines. What a pity the only real meaning of the expression should have become lost with the publicity given to this latest folly.
Kym Temby, Cornwall

The new Man Engine is actually built to honour its namesake. Specifically, it was built to commemorate the disaster in Levant in 1919, when the engine collapsed, taking its passengers with it. There's a short video about it at **themanengine.co.uk/the-original-man-engine**
– Daniel Bennett, editor

The Man Engine commemorates victims of a 1919 mining disaster

BBC FOCUS

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DISCOVERIES

DISPATCHES FROM THE CUTTING EDGE

APRIL 2018 | EDITED BY JASON GOODYER

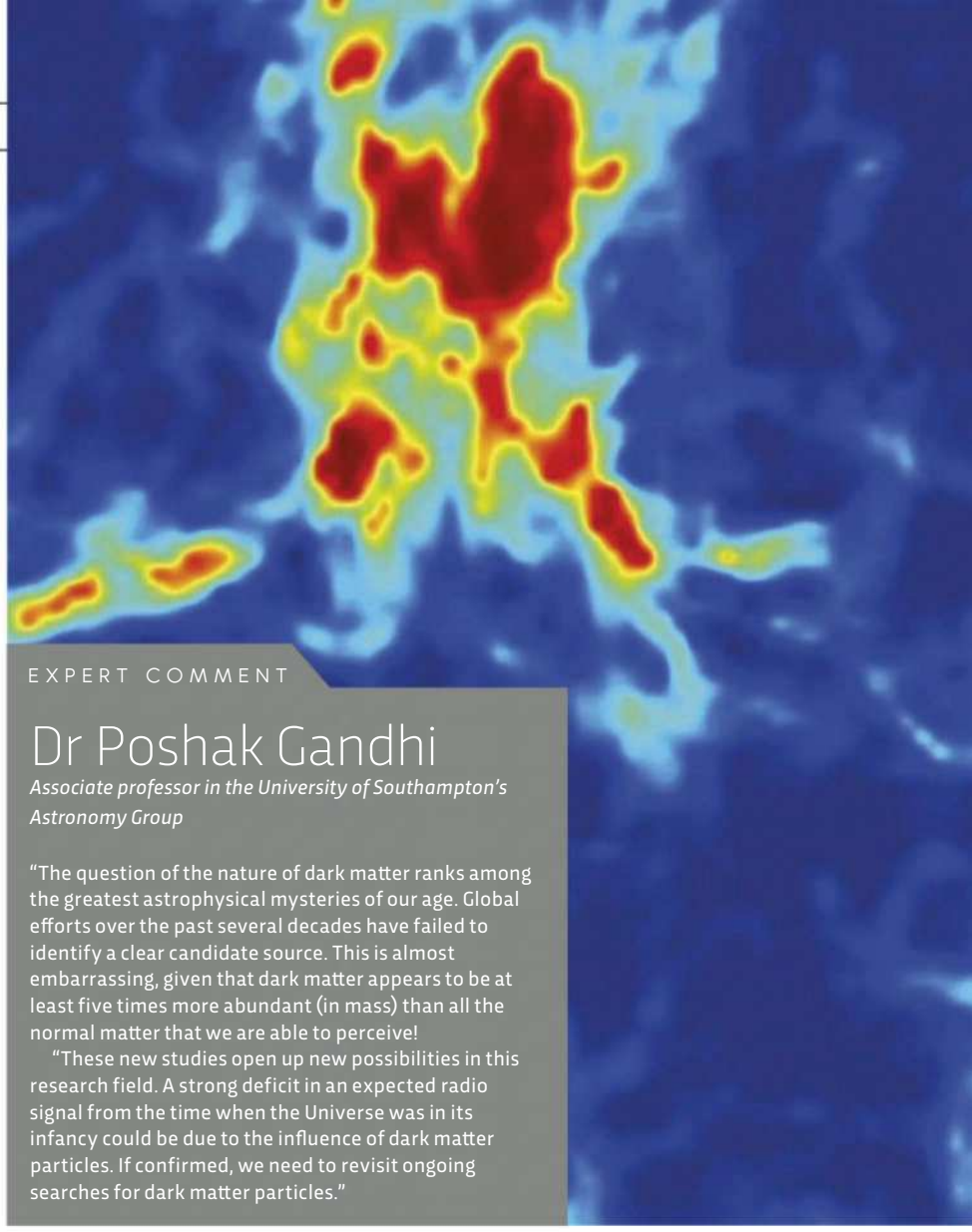
COSMOLOGY

LIGHT FROM THE EARLIEST STARS MAY PROVIDE FIRST DIRECT EVIDENCE OF DARK MATTER

Signals from stars that formed during the Universe's infancy may contain the 'fingerprints' of dark matter

Artist's impression of star formation in the early Universe

PHOTO: N R FULLER/NATIONAL SCIENCE FOUNDATION



Signals originating from the Universe's earliest stars contain new evidence about the nature of dark matter, said the international team of astronomers who detected them.

The signals, which date back more than 13 billion years to the period just after the Big Bang when the Universe's first stars were forming, were detected by the EDGES antenna – a radio spectrometer that's located at Australia's Murchison Radio-Astronomy Observatory (MRO). They hold a wealth of information that opens a new window on how early stars, black holes and galaxies formed. According to Tel Aviv University's Prof Rennan Barkana, they may also be able to shed some light on the nature of dark matter – the mysterious substance that makes up 85 per cent of the mass in the Universe.

"Dark matter is the key to unlocking the mystery of what the Universe is made of," said Barkana. "The existence of dark matter is inferred from its strong gravity, but we have no idea what kind of substance it is. Hence, dark matter remains one of the greatest mysteries in physics."

The researchers found the signals embedded in the cosmic microwave background – the electromagnetic radiation left over from the Big Bang that still permeates the Universe today. As stars began to form in the early Universe, light penetrated atoms in the primordial hydrogen gas – surrounding them, internally exciting them and causing them to absorb radiation from the cosmic microwave background at particular frequencies.

EXPERT COMMENT

Dr Poshak Gandhi

Associate professor in the University of Southampton's Astronomy Group

"The question of the nature of dark matter ranks among the greatest astrophysical mysteries of our age. Global efforts over the past several decades have failed to identify a clear candidate source. This is almost embarrassing, given that dark matter appears to be at least five times more abundant (in mass) than all the normal matter that we are able to perceive!

"These new studies open up new possibilities in this research field. A strong deficit in an expected radio signal from the time when the Universe was in its infancy could be due to the influence of dark matter particles. If confirmed, we need to revisit ongoing searches for dark matter particles."

IN SEARCH OF DARK MATTER

1933

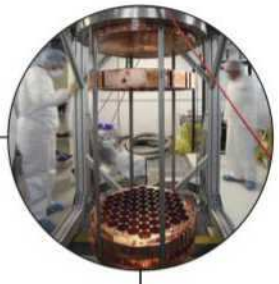
Swiss astronomer Fritz Zwicky proposes the existence of dark matter after noting a discrepancy between the calculated mass of the Coma galaxy cluster and the mass of visible matter.

1970

Cornell University's Vera Rubin notices that galaxies at the edge of the Universe move faster than expected. She suggests dark matter as the cause.

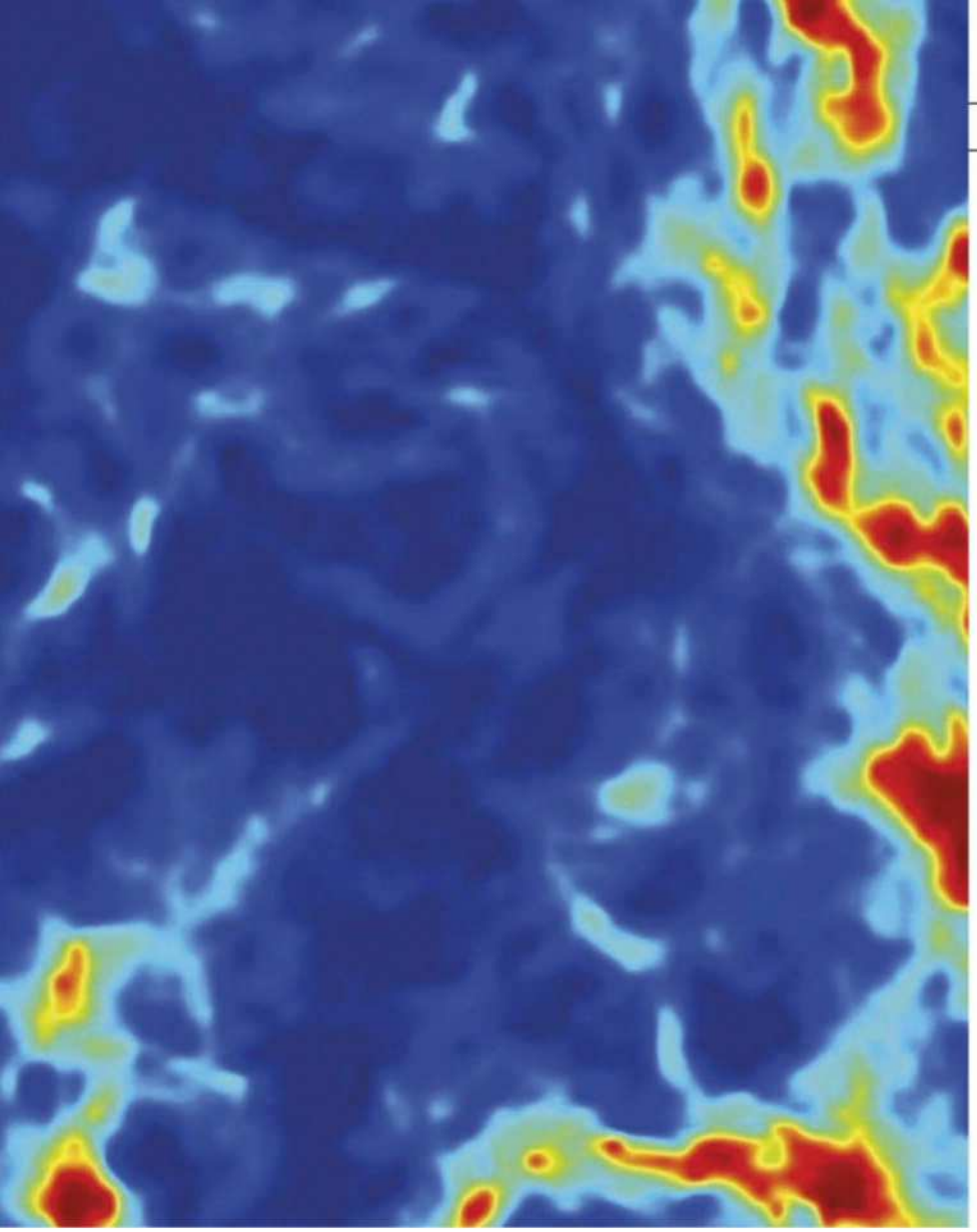
1981

Israeli physicist Mordehai Milgrom proposes that the mass of the Universe is correct, and that it's Newtonian mechanics that needs updating. He dubs the theory MOND, or Modified Newtonian Dynamics.



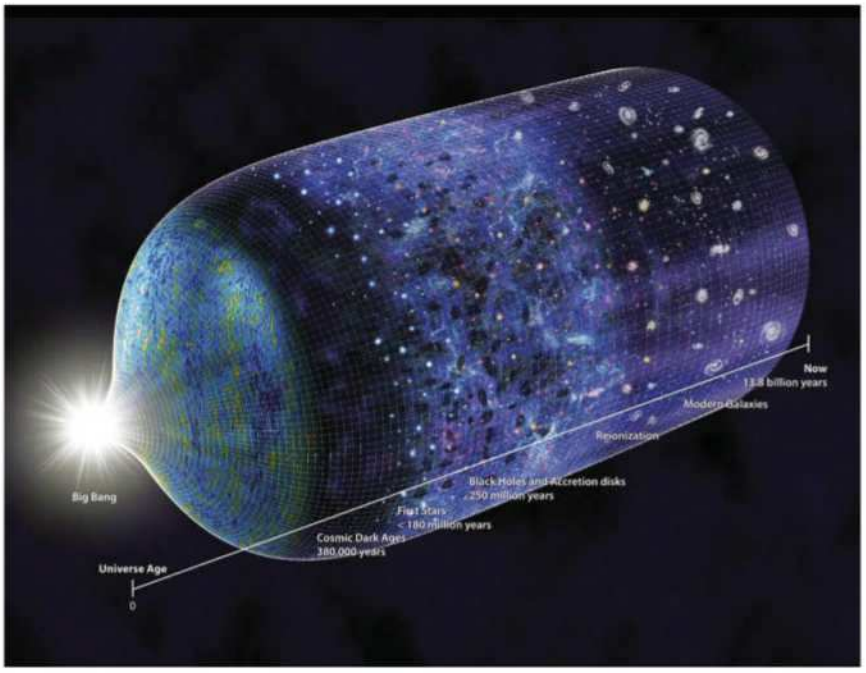
2009

Construction on the LUX experiment begins in South Dakota. The experiment aims to detect Weakly Interacting Massive Particles (WIMPs), a hypothetical particle candidate for dark matter.



LEFT: **The blue areas in this image show cooler regions where light from the first stars is thought to have interacted with dark matter**

BELOW LEFT: **Timeline of the Universe**



PHOTOS: PROFESSOR RENNAN BARKANA, NATIONAL SCIENCE FOUNDATION, GETTY X3

"THIS PROJECT SHOWS THAT A PROMISING NEW TECHNIQUE CAN WORK, AND HAS PAVED THE WAY FOR DECADES OF NEW ASTROPHYSICAL DISCOVERIES"

By locating these dips in frequency, the team was able to determine that the first stars were born just 180 million years after the Big Bang.

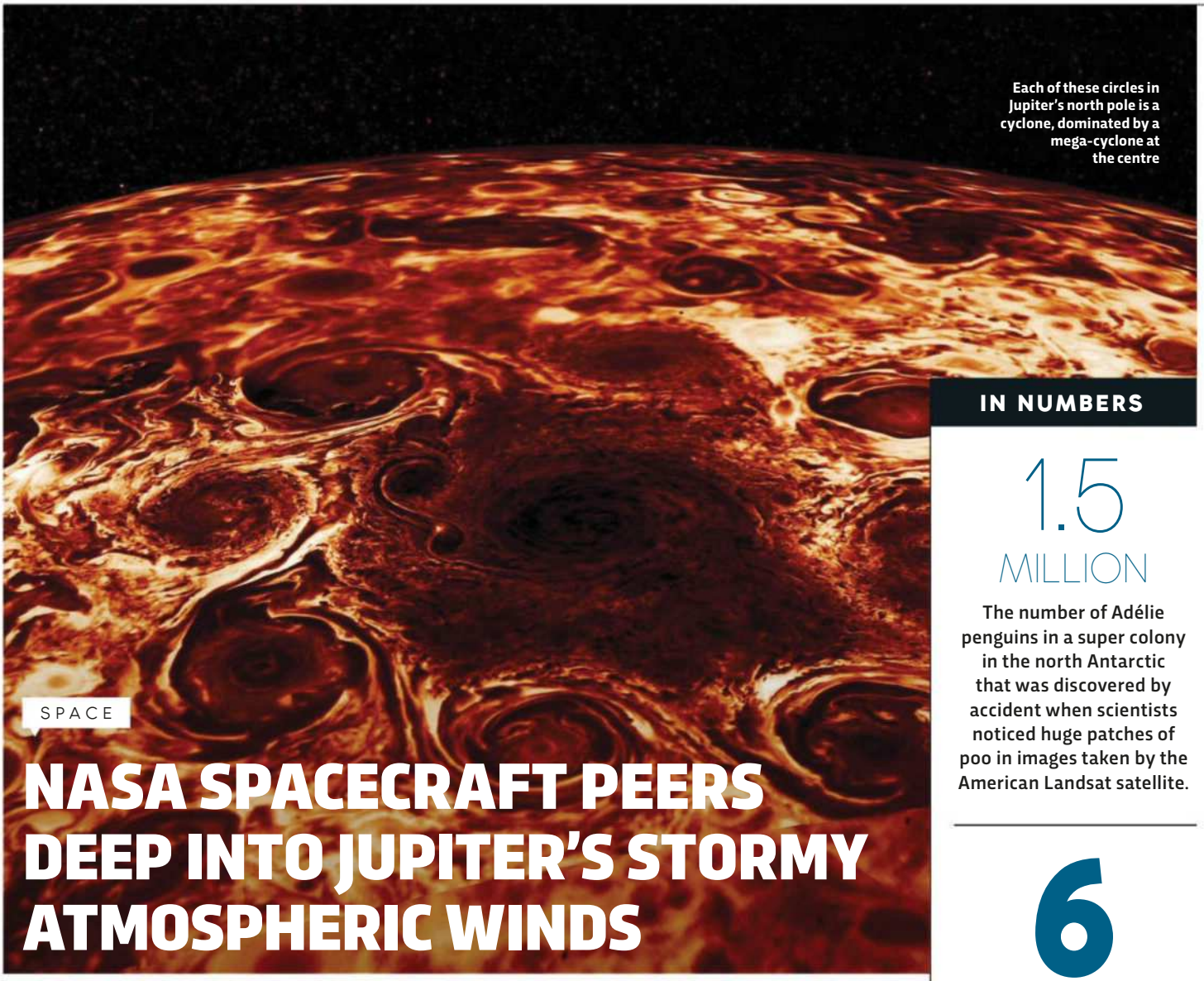
"It is unlikely that we'll be able to see any earlier into the history of stars in our lifetimes," said lead author Judd Bowman, of Arizona State University. "This project shows that a promising new technique can work, and has paved the way for decades of new astrophysical discoveries."

The signals also show that the gas in the early Universe was much colder than expected. According to a second paper written by Barkana, this could be due to the normal matter interacting with dark matter and losing energy.

"I realised that this surprising signal indicates the presence of two actors: the first stars, and dark matter," he said. "The first stars in the Universe turned on the radio signal, while the dark matter collided with the ordinary matter and cooled it down."

If he is correct, the finding will be the first direct evidence for the existence of dark matter. What's more, while many physicists have predicted that dark matter particles would be heavy – so-called Weakly Interacting Massive Particles, or WIMPs – this new discovery indicates that it's more likely to consist of low-mass particles no heavier than several protons.

The team is now waiting for researchers at other radio telescopes around the world to confirm their results.



Each of these circles in Jupiter's north pole is a cyclone, dominated by a mega-cyclone at the centre

SPACE

NASA SPACECRAFT PEERS DEEP INTO JUPITER'S STORMY ATMOSPHERIC WINDS

This breathtaking snap of Jupiter's tumultuous north pole was captured by the Jovian Infrared Auroral Mapper (JIRAM) instrument in NASA's Juno space probe on a recent flyby. It shows a swirling mass of cyclonic storms unlike anything else so far encountered in our Solar System.

Since entering Jupiter's orbit in July 2016, Juno has completed 10 passes over the planet, probing deep beneath the cloud cover into the atmosphere below and studying its auroras, structure and weather systems.

The new data shows turbulent cyclones that stretch deep down into the planet's atmosphere and persist far longer than any comparable systems found on Earth. Its north pole is dominated by a central cyclone surrounded by eight circumpolar cyclones, while its south pole contains a central cyclone surrounded by five smaller cyclones.

"These astonishing science results are yet another example of Jupiter's curve balls, and a testimony to the value of exploring the unknown from a new perspective with next-generation instruments," said Juno's principal investigator Dr Scott Bolton. "Juno is only about one-third the way through its primary mission, and already we are seeing the beginnings of a new Jupiter."

Preliminary analysis of other data collected by Juno suggests that beneath the stormy, swirling exterior the planet rotates as a single body, but has a liquid rather than solid core.

"This is an amazing result, and future measurements will help us understand how the transition works between the weather layer and the rigid body below," said Tristan Guillot, another of the Juno team. "Juno's discovery has implications for other worlds in our Solar System and beyond. Our results imply that the outer, differentially rotating region should be at least three times deeper in Saturn, and shallower in massive giant planets and brown dwarf stars."

IN NUMBERS

1.5 MILLION

The number of Adélie penguins in a super colony in the north Antarctic that was discovered by accident when scientists noticed huge patches of poo in images taken by the American Landsat satellite.

6 TONNES

The weight of the Hispasat 30W-6 satellite that was recently launched by a SpaceX Falcon 9 rocket – the largest ever put into geostationary orbit.

16 DAYS

How much earlier in the year spring now arrives in the Arctic, thanks to climate change over the course of the last decade.

PHOTOS: NASA/JPL-CALTECH, RAUL MARTIN, DR FABIEN KNOLL AT ARAID-DINOPOLIS/UNIVERSITY OF MANCHESTER

PALAEONTOLOGY

TINY 127-MILLION-YEAR-OLD FOSSIL HOLDS VITAL CLUES TO BIRD EVOLUTION

It looks like good things really do come in small packages: a baby Enantiornithes fossil the size of a cocktail sausage is helping a team at the University of Manchester to piece together the evolution of modern-day birds.

Enantiornithes were a group of prehistoric birds that lived during the Mesozoic era – the age of the dinosaurs. They were able to fly and looked much like modern birds, save for the fact that they had teeth, as well as clawed fingers on each wing.

The fossil in question was unearthed from the bottom of a lake in Spain several years ago, but recent analysis using high-powered particle accelerators known as 'synchrotrons' has enabled researchers to picture the tiny specimen at a submicron level, observing the bones' microstructures in extremely fine detail. It is around 127 million years old, less than 5cm long and would have weighed less than 10g when it was alive. As the bird died shortly after birth, it provided the team with a rare chance to analyse the bone structure and development of the species.

"The evolutionary diversification of birds has resulted in a wide range of hatchling developmental strategies and important differences in their growth rates," said Fabien Knoll, who led the research. "By analysing bone development we can look at a whole host of evolutionary traits."

The researchers found the baby bird's breast bone was still largely made of cartilage and had not yet developed into hard, solid bone when it died, meaning it wouldn't have yet been able to fly. This may indicate that it was 'altricial', or heavily reliant on its parents' care at a young age, they say.

"This new discovery, together with others from around the world, allows us to peek into the world of ancient birds that lived during the age of dinosaurs," said Luis Chiappe from the Los Angeles Museum of Natural History. "It is amazing to realise how many of the features we see among living birds had already been developed more than 100 million years ago."

TOP: **Particle accelerators let scientists study the bones of the fossil**

RIGHT: **Artist's impression of the young dinosaur, compared to the size of a cockroach**

THEY DID WHAT?!

CHICKEN MADE TO RUN AROUND A RACE TRACK

What did they do?
Researchers at Australia's Queensland Museum made a real-life chicken run by making a race track for domestic hens and measuring the movements in their hips as they sped around it.

Why did they do that?
The team were interested in figuring out how two-legged dinosaurs moved. As there are only static records of dinosaur gaits, such as footprints and fossils, the researchers turned to the extinct reptiles' closest living relatives – birds.

What did they find?
Birds' gait, and probably that of dinosaurs, varies according to the size of their bodies. Larger animals run in a more upright position, with a longer stretch in their legs. *T. rex* was likely to have run much like a giant ostrich, the researchers say.

GENETICS

GENES THAT DETERMINE FACIAL FEATURES IDENTIFIED

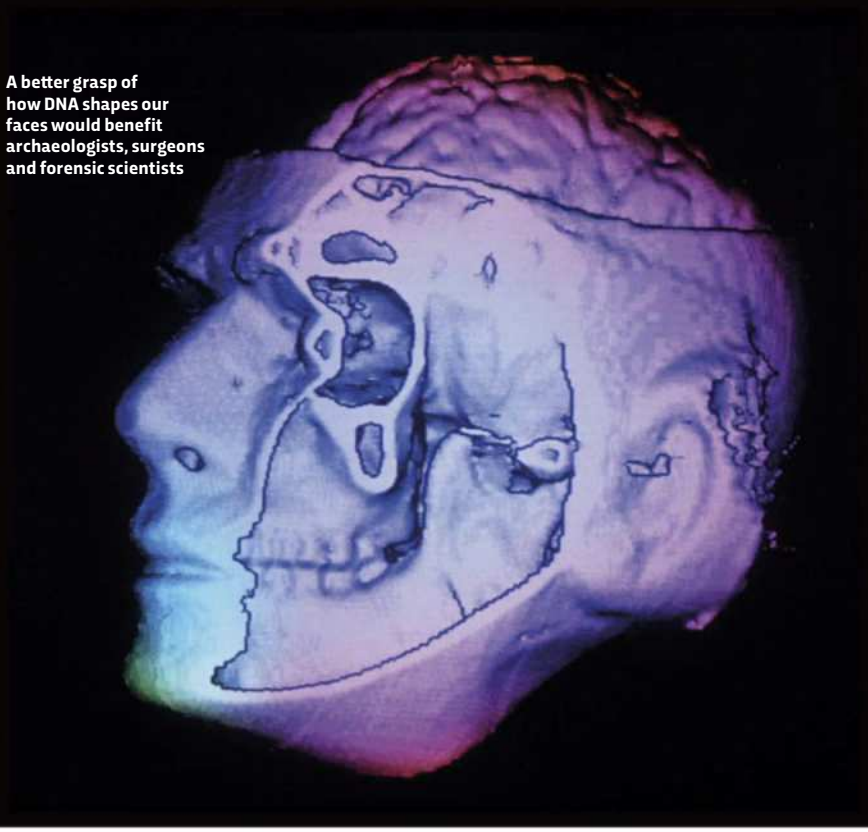
At the University of Leuven in Belgium, a team of researchers has identified a set of 15 genes that they believe determine our facial features. This research could benefit surgeons attempting to reconstruct the faces of burns and trauma patients, archaeologists who've unearthed human remains, and police forensic investigators who only have DNA evidence to identify victims.

In the past, scientists selected specific features, such as the distance between the eyes or the width of the mouth, then looked for a connection between these features and the genes. A number of genes have been found using this method, but it's limited by the fact that only a small set of features are tested.

In the new study, the researchers used a database of DNA along with 3D images of subjects' faces, which were automatically subdivided into small segments. By comparing similar facial features to similar stretches of DNA, they were able to determine the genes responsible for determining the shape of several facial features. Using this method, the scientists were able to identify 15 locations in our DNA that are active while our faces are developing in the womb. Of these 15 genes, 7 are linked to shaping the nose.

"A skull doesn't contain any traces of the nose, which only consists of soft tissue and cartilage. Therefore, when forensic scientists want to reconstruct a face on the basis of a skull, the nose is the main obstacle," said the University of Leuven's Dr Peter Claes. "If the skull also yields DNA, it would become much easier in the future to determine the shape of the nose."

The team now plan to further refine their work, drawing on larger databases of DNA and facial images.



A better grasp of how DNA shapes our faces would benefit archaeologists, surgeons and forensic scientists

ZOOLOGY

RHYTHMIC MONKEY VOCALISATIONS HINT AT EVOLUTION OF HUMAN SPEECH

The sounds made by marmoset monkeys are built from individual syllables of fixed length, much like human speech, researchers at the University of Tübingen, Germany have found. Such a rhythm may have been a key step in the evolution of true speech, they say.

Whether saying a short word such as 'hi' or a longer one such as 'floccinaucinihilipilification,' everything humans say is made up of smaller units of sound lasting an average of one-seventh of a second, regardless of the language spoken. This rhythm is inherent in our production of syllables, and is due to the structure of our voice boxes and the neural processes that control speech. The Tübingen team has now found that the vocalisations of marmosets, a type of small primate found in South America, also share this feature. They recorded thousands of the monkeys' cries in a sound chamber, interrupting them at random intervals with bursts of white noise which caused them to fall quiet.

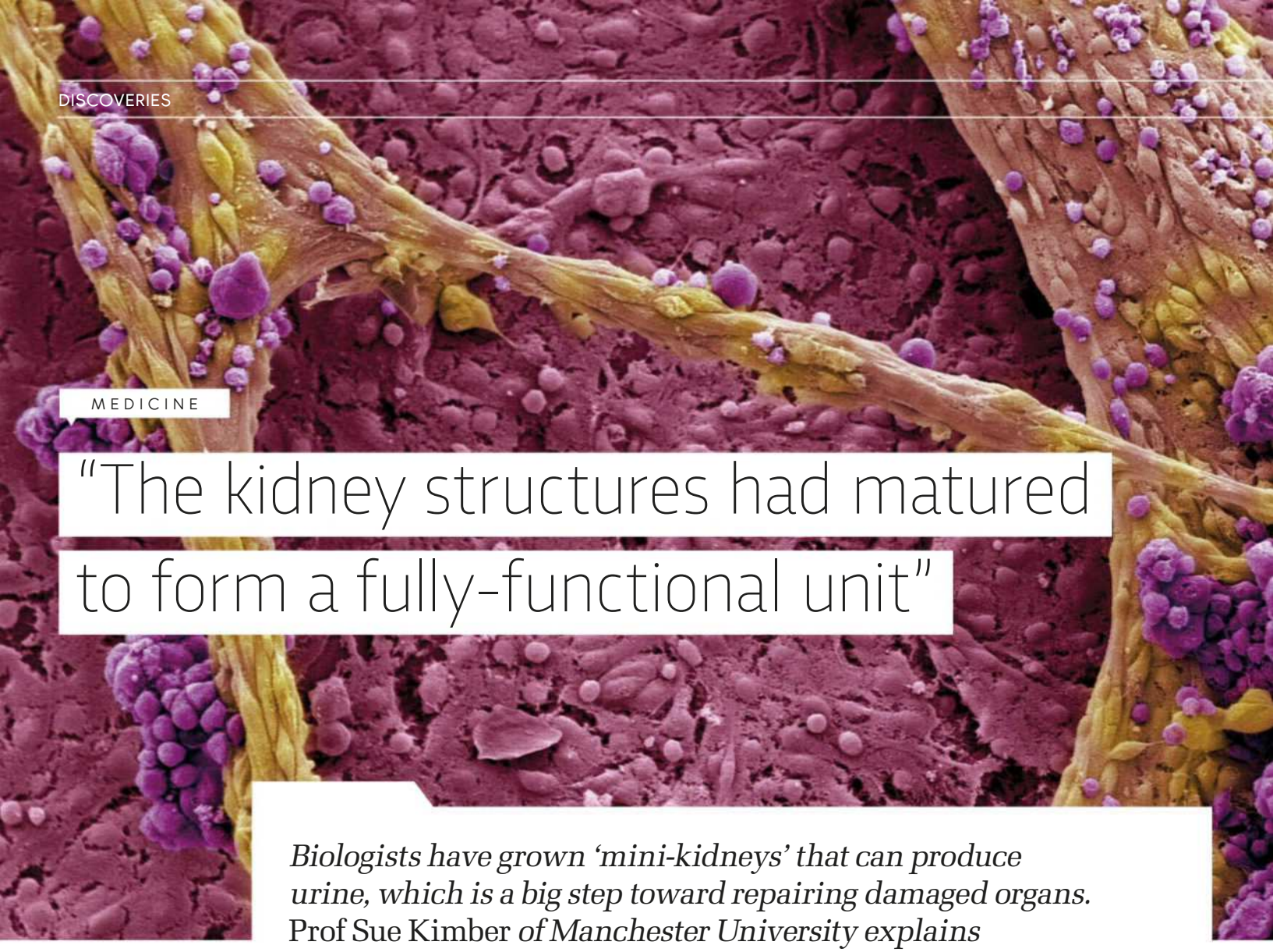
"The marmosets' 'phee' cry had so far been considered part of their basic vocabulary, alongside the 'tsik' and 'ekk'," said Thomas Pomberger, co-author of the paper in the journal *Current Biology* detailing the research. "[But] we observed that they would stop right in the middle of their 'phee' calls when disrupted with noise. Moreover, that would only happen at specific points within the call."

This means that the long 'phee' call is made up of small units about the same length as the 'tsik' or 'ekk' call – around 100ms. It's essentially the monkey equivalent of a multisyllable call.

"Until now, the supposed existence of the long 'phee' has not allowed for the conclusion that we can draw now," said Dr Steffen Hage, who led the research. "Like us, marmoset monkeys have a 'hardwired' rhythm that controls their vocalisation. It is even similarly fast."

Marmoset cries are made up of short syllables of a roughly similar length – just like human speech

PHOTOS: GETTY X2. ILLUSTRATION: JOE WALDRON



MEDICINE

"The kidney structures had matured to form a fully-functional unit"

Biologists have grown 'mini-kidneys' that can produce urine, which is a big step toward repairing damaged organs. Prof Sue Kimber *of Manchester University explains*

ABOVE: **Pluripotent stem cells can differentiate, which means they can turn into any type of cell in the human body. Here, stem cells (orange and purple) have become differentiated**

What does the kidney do?
In normal metabolism, waste products are deposited in the blood and need to be removed, so the kidney's job is to get rid of the things we don't want. But at the same time we have all sorts of valuable nutrients, salts and glucose and so on, and don't want to get rid of those in the urine, so the kidney has to make sure it reabsorbs those nutrients if they're filtered out. Parts of the kidneys do different things in this filtering and reabsorbing job, so we had to make the different parts.

How did you grow 'mini-kidneys'?
We started out with human pluripotent stem cells [cells that can become any type of cell] and made them become specialised cells of the kidney. In this protocol, you get these different cell types being produced and then they interact with each other and almost start to develop autonomously into immature kidney structures in the Petri dish. We can make them form into little 3D structures on a suspended membrane. We took those developing cells and put them just under the skin of a mouse. We left them there for three months and were very pleased to find that the kidney structures had matured substantially. You could see cells of the blood system and the working filtration element of the kidney– the glomerulus – was maturing to form a fully functional unit.

How do you know they work?
We injected a fluorescent dye into the blood system, then looked an hour later and found that this fluorescent molecule had been filtered from the blood and ended up inside the tubules connected to the filtering unit. What that meant was that it had gone from the blood, been filtered by the glomerulus, and ended up in the tubules. These tubule cells have a re-uptake function, so that suggests they also have some functionality. In our developing kidneys, we have these different elements that should lead into a ureter, the final tube that takes the urine to the bladder. In our structures, we do not – as far as we can see – develop a ureter. So, if we were going to make a fully functional kidney, we would need a way out for the urine. When will the clinical trials start? I think probably a decade.

Why grow kidney cells?
We could use them to repair damaged kidneys.

PHOTOS: SCIENCE PHOTO LIBRARY X2. ILLUSTRATIONS: JOE WALDRON

BELOW: **Computer-generated image of a kidney. The ureter, from which urine exits the kidney, can be seen at the bottom of the organ**

The difficulty is, if you just inject them into the kidney, they're not necessarily going to go to the right place. Can they survive? We don't know. They may not be able to continue to develop and take over the function of the damaged kidney. There are a number of genetic diseases where the kidneys don't develop correctly, and we're also using this technology to identify pathways that don't occur properly, so we can identify potential drug targets. Globally, about 2.6 million people need dialysis or kidney transplantation for end-stage kidney disease each year, and probably about 2.2 million people die because they can't get treatment. But kidney transplants only extend life to a limited extent. There's a shortage of donor kidneys, so this is a major unmet clinical need requiring an alternative solution.

MARTIAL ARTISTS

Hi-yah! A team in the US have found that after three months of training in tae kwon do, school-age children were more disciplined, better behaved and performed better in maths tests than children who took regular PE classes.

WINE DRINKERS

Want a healthy set of gnashers? Break out the Beaujolais! Chemicals known as polyphenols that are found in red wine can help fight harmful bacteria in the mouth and keep teeth healthy, Spanish researchers have found.

GOOD MONTH

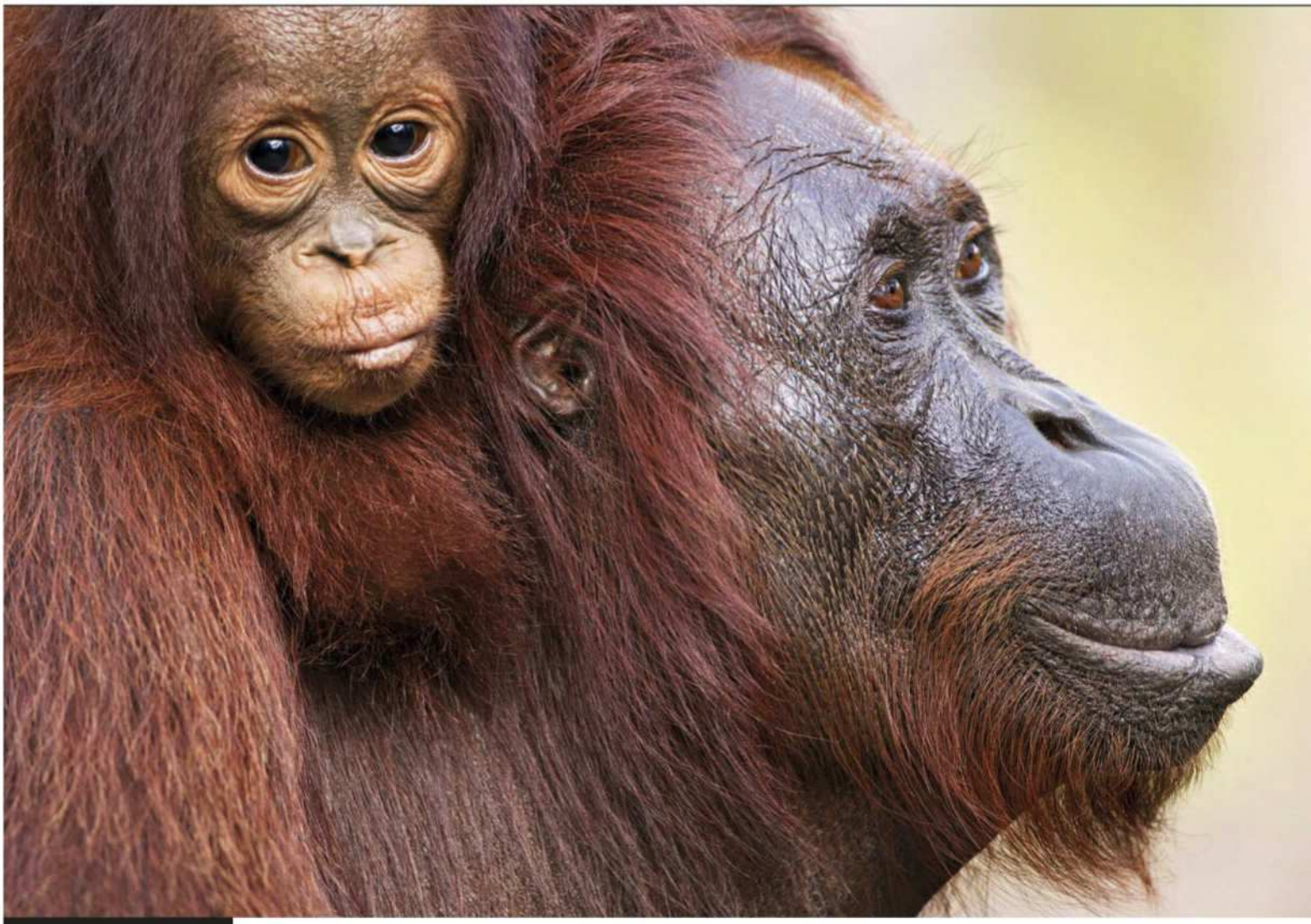
BAD MONTH

ONLY CHILDREN

From sharing a bedroom to wearing hand-me-downs, it can seem that there are no perks to having siblings. But Canadian researchers have found that being part of a large brood can help youngsters to become more caring and empathetic.

SELFIE ADDICTS

Researchers at Rutgers University have found that taking a photo from around 30cm from the face can make your nose appear up to 30 per cent wider than taking the same shot from about 2m away. The effect is akin to looking in a funhouse mirror, they say.



CONSERVATION

BORNEAN ORANGUTAN POPULATION HALVED IN THE LAST TWO DECADES

Logging, hunting and the demand for palm oil have led to the estimated loss of nearly 150,000 Bornean orangutans – almost half of the total population – since 1999, a huge international study has found. The comprehensive study combined observations from 36,555 orangutan nests collected by 38 different institutions. It estimated that a total of 148,500 animals were lost between 1999 to 2015.

"The decline in population density was most severe in areas that were deforested or transformed for industrial agriculture, as orangutans struggle to live outside forest areas," said Maria Voigt of the Max Planck Institute, Germany, who led the research. "Worryingly, however, the largest number of orangutans were lost from areas that remained forested during the study period. This implies a large role of killing."

"THE LARGEST NUMBER OF ORANGUTANS WERE LOST FROM AREAS THAT REMAINED FORESTED"

Based on predicted future reductions in forest cover and the assumption that orangutans ultimately cannot survive outside forest areas, the researchers say that 45,000 more orangutans could be lost over the next 35 years if the situation isn't addressed.

"Orangutans are flexible and can survive to some extent in a mosaic of forests, plantations, and logged forest, but only when they are not killed," said Prof Serge Wich of Liverpool John Moores University, who co-authored the paper detailing the research. "So, in addition to protection of forests, we need to focus on addressing the underlying causes of orangutan killing. The latter requires public awareness and education, more effective law enforcement, and also more studies as to why people kill orangutans in the first place."

PHOTOS: GETTY, NASA/CHANDRA/CXC

ASTRONOMY

DOZENS OF GARGANTUAN BLACK HOLES FOUND IN DISTANT GALAXIES

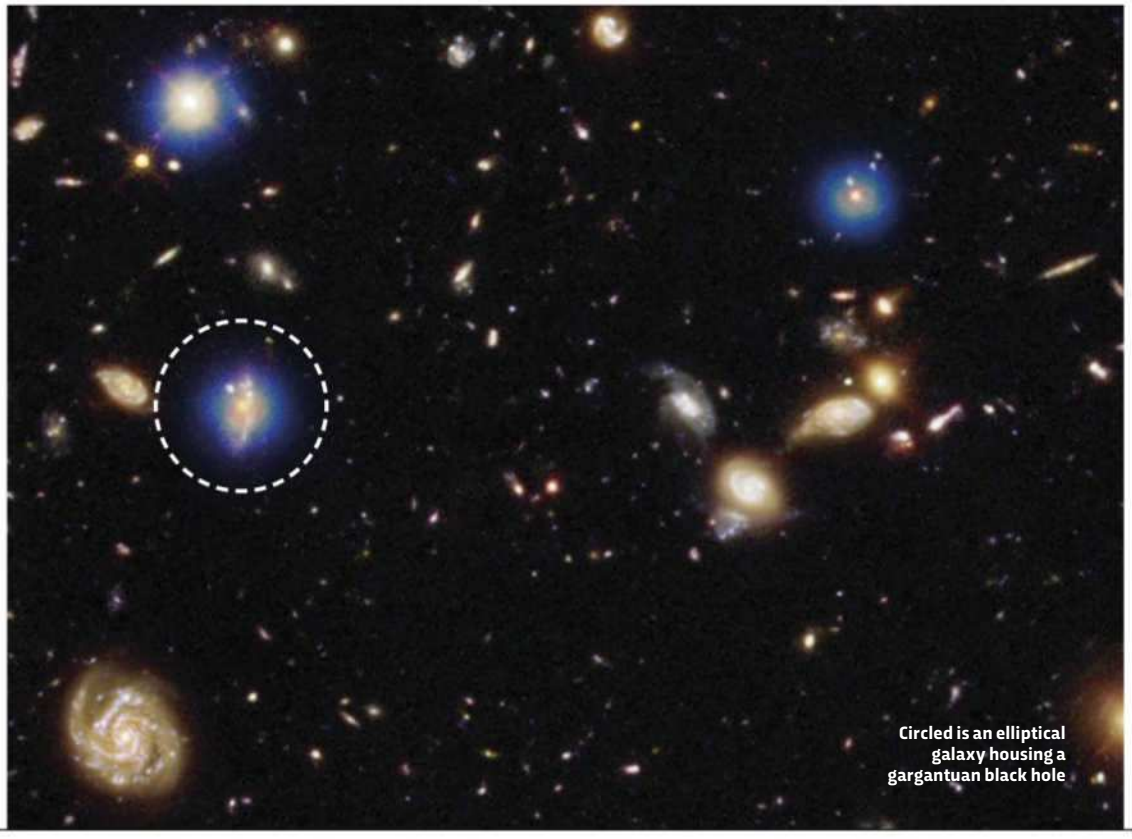
An international team of astrophysicists has found some of the biggest black holes ever discovered lurking in a galaxy cluster 3.5 billion light-years from Earth.

The so-called 'ultramassive' black holes were found amongst 72 galaxies located at the centre of the Universe's brightest and most massive galaxy clusters using instruments onboard NASA's Chandra X-ray Observatory. The astronomers estimated the masses of the black holes detected by analysing radiowave and X-ray emissions. They found that almost half of the sample's black holes are at least 10 billion times more massive than our Sun.

"We have discovered black holes that are far larger and way more massive than anticipated," said Mar Mezcua, a postdoctoral fellow at the Institute of Space Sciences in Spain. "Are they so big because they had a head start, or because certain ideal conditions allowed them to grow more rapidly over billions of years? For the moment, there is no way for us to know."

Black holes in distant galaxy clusters such as these have a significant impact on their galactic neighbourhoods and the entire Universe for billions of years, the researchers say.

"They are the most powerful objects in the Universe, and they are anything but quiet," said Prof Julie Hlavacek-Larrondo of the University of Montreal, who was also involved in the research. "Galaxies are the building blocks of our Universe, and to understand their formation and evolution, we must first understand these black holes."



Circled is an elliptical galaxy housing a gargantuan black hole

THINGS WE LEARNED THIS MONTH

TATTOOING IS AT LEAST 5,000 YEARS OLD

Pictures of a wild bull and a Barbary sheep have been found tattooed on the upper right arm of Gebelein Man – a naturally mummified body, dating from between 3351 and 3071 BC, that's currently on display at the British Museum. The marks look like dark smudges in natural light but were revealed to be tattoos using infrared imaging.

CYCLING CAN SLOW DOWN AGEING

Regular cycling can help to maintain healthy muscle mass, immune system function and cholesterol and testosterone levels well into old age, researchers at the University of Birmingham have found. Time to break out the Lycra?

FAKE NEWS SPREADS FASTER THAN THE TRUTH

After analysing the progress of 126,000 news stories on Twitter, a team at MIT has found that 'fake news' – stories containing deliberate falsehoods or exaggerations to drive website traffic – spreads around six times faster than accurately reported news stories.

"CAN YOU REALLY GET FIT BY EXERCISING FOR TWO MINUTES A WEEK?"

DR MICHAEL MOSLEY

Michael is a science writer and broadcaster, who presents *Trust Me, I'm A Doctor* on BBC Two. His latest book is *The Clever Guts Diet* (£8.99, Short Books).

The great thing about making science documentaries is that you constantly discover things that surprise you. I first came across High Intensity Interval Training (HIIT) more than five years ago while making a documentary for *Horizon*. At the time, I learned that just three minutes a week of intense cycling could greatly improve aerobic fitness and blood sugar control.

I kept in touch with the scientists, and was delighted to get another chance to try out HIIT. This time it was for a recent BBC documentary, *The Truth About Getting Fit*, and the novelty was that the HIIT protocol was now even shorter.

Dr Neils Vollaard at Stirling University has research showing that just two minutes of intense exercise a week (two bursts of 20 seconds, three times a week) would be enough to give the unfit a significant boost.

His studies have been done in labs, but we wanted to see if you could get the same results in an office. So we installed an exercise bike in a London office and asked six workers to do five weeks of Vollaard's HIIT regime.

Before they started, Vollaard assessed their aerobic fitness by measuring their VO2 max in the lab. Get an estimate of yours here: **bit.ly/aerobic_fitness**

VO2 max is a great predictor of how well you're ageing and your life expectancy. The attraction of HIIT is it can produce the same sort of improvements in VO2 max that you'd get from longer sessions of less vigorous activity. "To achieve the same results we get with HIIT, you'd have to run at a decent pace for 45 minutes, three times a week," Vollaard told me.

Why? Well, Vollaard says that when you do a short, high-intensity sprint your body breaks down glycogen, a form of sugar stored in your muscles. This sets off a cascade of other reactions, including the release of signalling molecules. You then have a breather before your next short sprint, when these signalling molecules are activated. This in turn helps stimulate the growth of other muscle, like heart muscle.

As the cycling sprints require maximum effort, you will have to increase the resistance on the exercise bike as your fitness improves.

That's the theory. But how well would it work in practice? Five weeks after our first set of tests, we returned to see how our office workers had got on. Everyone improved, and the group as a whole saw an improvement in fitness levels of 11 per cent. If they kept it up, this would mean a reduction of around 20 per cent in the risk of developing heart disease.

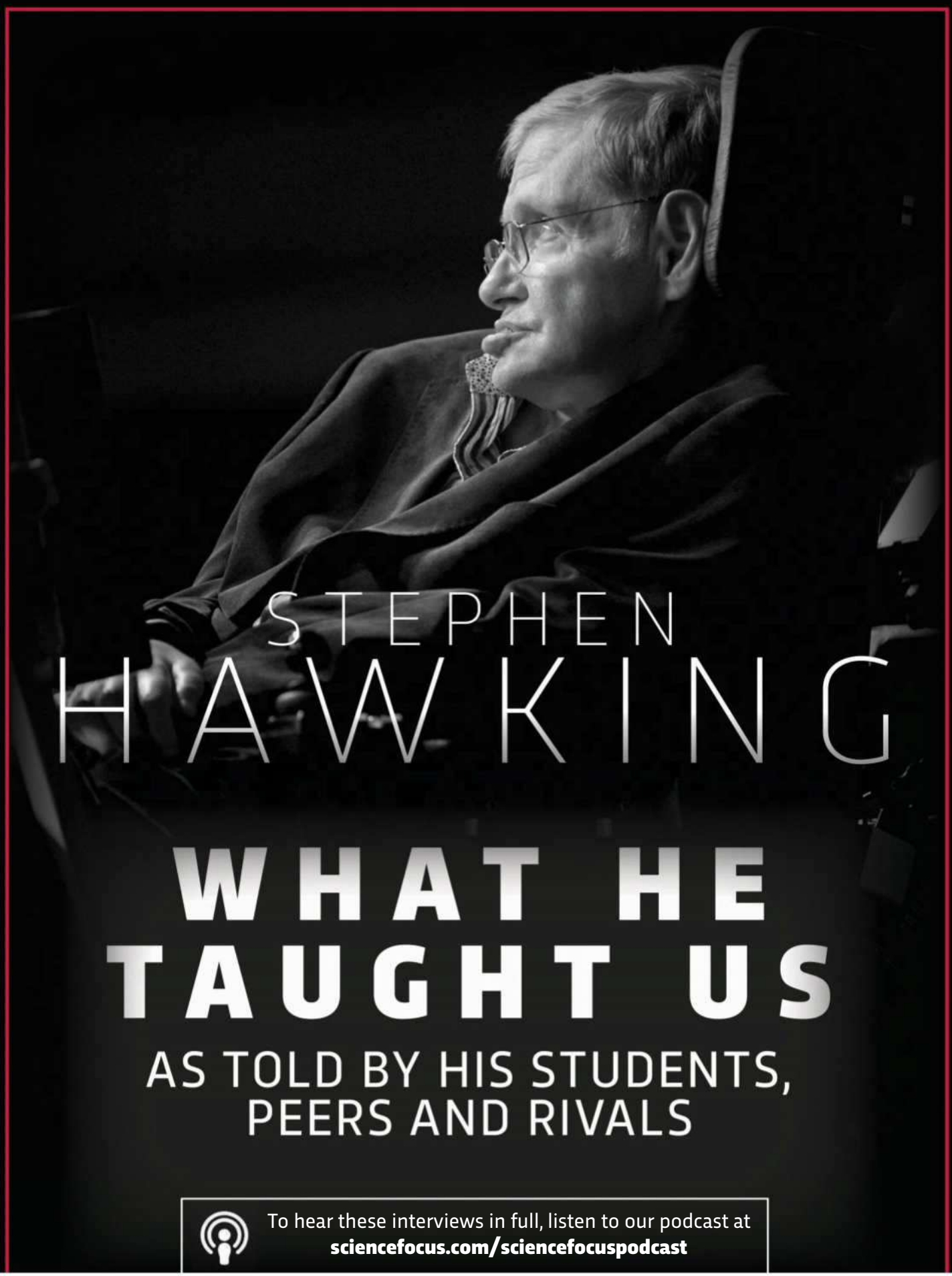
HIIT isn't for everyone. If you're unfit then you should start slowly, doing just one 10-second sprint per session for the first week or so. If you are on medication, are injured or have concerns about your heart, then you should consult your GP.

For Vollaard's regime, you will need an exercise bike where you can easily vary the resistance. Start by getting on the bike and doing a short warmup of gentle cycling. After a minute or so begin pedalling fast, then crank up the resistance – it should be high enough so that after 15 seconds your thighs begin to feel it and the speed at which you are pedalling slows because your muscles are beginning to fatigue. After your first burst of fast sprinting, drop the resistance and do three minutes of gentle pedalling. Then do the 20-second sprint again.

It is important that each 20-second workout involves maximum effort. Finish with a couple of minutes of gentle cycling before stepping off the bike.

No access to a bike? You can run up stairs for 20 seconds or put in short, flat-out sprints when jogging.

ILLUSTRATION: KOUZOU SAKAI



STEPHEN HAWKING

WHAT HE TAUGHT US

AS TOLD BY HIS STUDENTS, PEERS AND RIVALS

To hear these interviews in full, listen to our podcast at **sciencefocus.com/sciencefocuspodcast**

PHOTO: ALAMY

DR CHRISTOPHE GALFARD

Writer, science communicator and former PhD student of Prof Stephen Hawking.

"I was Hawking's PhD student from 2000 to 2006 at Cambridge University. I wasn't really daunted by his celebrity – in the academic world, that's kind of irrelevant – but what was daunting was that he was extremely hard to work with, in the sense that he wasn't interested in scientific small talk. He only wanted to tackle the big questions: the hardest problems in theoretical physics. He had a rare intuition that I think is possessed by only a handful of scientists every century: he could see beyond the maths to the bigger picture. I worked with him on a type of string theory called M-theory that tries to combine everything we know about the Universe, and later we worked on the black hole information paradox, where black holes seemed to be leaking information from the Universe. Each time I showed him some new results, he would immediately know where to point the finger.

I got to spend a lot of time with him – his philosophy was to spend as much time as possible with his colleagues and students. While he didn't do scientific small talk, he was always lively to be around. He'd joke and talk about movies and which restaurants to check out – he'd take us out to dinner for our birthdays. He was generous with his thoughts and his time, and his joy of life.

It's always when you're at the start of something that it's the most fulfilling – when you're just beginning to understand things, and there's someone there to hold your hand and show you the way. He was that person for me, and the six years I spent with him were probably the richest and fullest of my life."

ABOVE: **Hawking's work shone a light on black holes**

RIGHT: **Hawking's tastes weren't always highbrow – he loved the film *Babe***

Prof Stephen Hawking A BRIEF HISTORY

1942

Born 8 January in Oxford to Frank and Isobel Hawking. He is the eldest of four siblings. In 1950 the family moves to St Albans, where Hawking attends the private St Albans School.

1958

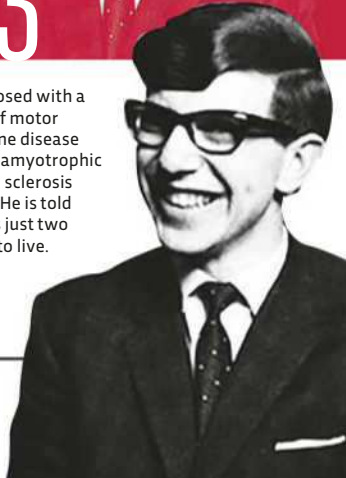
Assisted by their maths teacher Dikran Tahta, Hawking and a group of schoolfriends build a working computer from a telephone switchboard and some old clock parts.

1962

Graduates from University College, Oxford with a first-class honours degree in natural sciences. He begins studying for a doctorate in cosmology at Trinity Hall, Cambridge.

1963

Diagnosed with a type of motor neurone disease called amyotrophic lateral sclerosis (ALS). He is told he has just two years to live.



PROF MARIKA TAYLOR

Theoretical physicist at the University of Southampton and former PhD student of Prof Stephen Hawking.

PHOTOS: GETTY X2, SHUTTERSTOCK, HERTS ADVERTISER

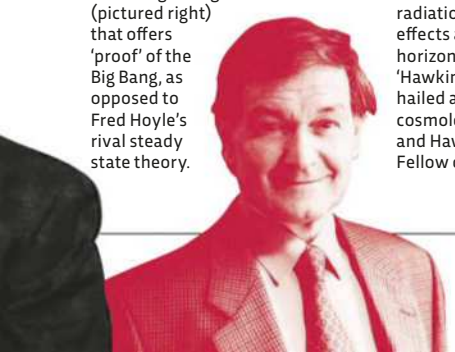
"I first met Stephen in 1995, to discuss options for my PhD. I was nervous, but he jumped straight into a conversation about physics, and he sent me away with a list of papers to read about string theory. He was already a celebrity by this point. When I was an undergraduate, he was living in an apartment just behind my student house, and friends would come to my room just to get a glimpse of him coming and going.

Because of his medical issues, Stephen couldn't work problems out on paper. So his PhD students were really important to him – they could help do the calculations and develop his ideas. We were dragged right to the forefront of research.

During lunch, the conversation would often drift into politics, movies and music. His tastes were both highbrow and lowbrow. He liked arthouse films, but I remember him saying how much he enjoyed *Babe* – the movie about the talking pig – when we were all saying how rubbish it was. He had a wonderful smile, and because he was forced to communicate so concisely with his synthesiser, he had a gift for one-liners. Once, we were in a pub and he turned up the volume on his synthesiser and announced "I'm coming out". He was referring to a change of mind he'd had on the black hole information paradox, but he clearly enjoyed winding up the entire pub. I'm going to miss his sense of warmth, his humour, his enthusiasm and spark."

1970

Publishes an essay with cosmologist Roger Penrose (pictured right) that offers 'proof' of the Big Bang, as opposed to Fred Hoyle's rival steady state theory.



1974

Publishes a paper showing that black holes emit radiation due to quantum effects around their event horizon. The discovery of 'Hawking radiation' is soon hailed as a major cosmological breakthrough, and Hawking is made a Fellow of the Royal Society.

1979

Becomes the first recipient of the Albert Einstein Medal, awarded annually for "scientific findings, works, or publications related to Albert Einstein".

1981

Hawking is made a Commander of the British Empire (CBE) in the New Year Honours list.

1982

Decides to start writing a book that will explain the history of the Universe in layman's terms for a mass readership. The first draft of *A Brief History Of Time* is completed in 1984.

DR HELEN CZERSKI

Physicist and BBC science presenter whose most recent series was Colour: The Spectrum Of Science.

"I was given *A Brief History Of Time* when I was young, about 11 or 12. What was interesting about having read it at that age is that it was so clear. All these ideas that are intuitively quite weird and difficult just made sense. I think when I was growing up I never thought these things about time dilation and gravitational weirdnesses that you get in General Relativity seemed strange, because the first time I'd come across them they'd been so clearly explained that they never became weird, which is a huge start in a lot of ways. I think possibly the book had an influence on a lot of physicists because it set the ideas up as part of your world, instead of being something weird and outside it. Because the explanation was so clear, you couldn't miss what it was saying.

Not all good scientists have been good communicators, not all great scientists have been great communicators. But there is a very strong history that started in places like the Royal Institution where people stood up and said what they thought. He was part of the tradition. There's a long list of people who thought so clearly that communication was straightforward. I think that's the key. The key to great science is the same as the key to great communication, which is thinking clearly about what you are doing and being able to prioritise ideas. When those two things go together, you have something powerful. Hawking's was an important voice. There has been a perception that science is somehow separate from society, and he showed clearly that this is not the case."

JIM AL-KHALILI

Recipient of the inaugural Stephen Hawking Medal for Science Communication.

"The first time I met Stephen I was introducing him to 6,000-odd people at the Albert Hall. You could hear a pin drop. He was talking about cosmology and his life. He could have just sat on stage and played a recording, but he was adamant not to be impersonal. Though each paragraph had to be pre-recorded, he had to activate it to get it going. He controlled the flow and the slides, rather than just sit there to be looked at.

There's a pleasure that's derived from finding something out and then telling everyone else about it. What's the point of learning how the Universe works if you don't tell people? I couldn't imagine just publishing your findings in a paper that half a dozen people are going to read and then forget about. I want to shout it from the rooftops. And that's what Stephen liked to do.

I was an undergraduate in the 80s, before *A Brief History Of Time* came out. There were popularisers of science, but popular science books were niche. *A Brief History Of Time* changed the game. Everybody wanted a copy on their coffee table. Until then it felt like it was pretty much: "If you're smart, do the smart stuff. Leave the communicating to those who haven't got it in them to do the research." Stephen changed that with the publication of one book. He changed the game."

1986

With his speech now having seriously deteriorated due to his ALS, Hawking begins to communicate via a computer voice synthesiser called 'the Equalizer'. At first he punches buttons to select words from a list, but as his condition worsens, the equipment is modified so that he can move a cursor using his cheek muscles.

1988

A Brief History Of Time is published and becomes an instant bestseller. To date, the book has sold over 10 million copies and been translated into at least 35 languages. In 1992, a biographical film produced by Steven Spielberg was released on VHS.

1993

Hawking makes an appearance – in hologram form – on *Star Trek: The Next Generation*. Over the next 25 years, he will go on to appear in several episodes of *The Simpsons*, *Futurama* and *The Big Bang Theory*.

2006

Hawking says that, faced by the multiple existential threats of climate change, mass extinction and nuclear war, space exploration – and future colonisation of other planets – is crucial if the human race is to survive.

2009

Awarded the Presidential Medal of Freedom – the United States' highest civilian honour.

LORD MARTIN REES

Astronomer Royal, cosmologist and astrophysicist.

"I was two years junior to Stephen and joined the research group in Cambridge when he was already doing his PhD. I got to know him at the time when he found out that he had this fatal disease and was already walking with a stick. At that time his life expectancy was low and many people didn't think he would even finish his PhD. As he himself said, when he finished his PhD and got married his gloom lifted. He realised that he did have prospects.

He clearly had great mathematical ability, insight and determination. I think scientifically he will rate as one of the key people who has pushed forward our understanding of gravity in the last 50 years. In particular, for understanding black holes better. The paper he wrote in 1974, the so-called *Black Hole Explosions* paper, was important as the first quantitative attempt to link together Einstein's General Relativity with the microworld of the quantum. That paper has implications that are still being debated today.

Another breakthrough came when his book became a huge bestseller – to his and everyone's surprise. That catapulted him to international celebrity and made people interested in him as a personality, someone who despite having an imprisoned body was roaming the cosmos. This also gave him a further stimulus to engage in outreach events.

I think one can learn from Stephen that there are huge satisfactions from doing science. The subject that he chose is still immensely challenging and fascinating to a younger generation who will follow on and extend his work."

DR LEONARD MLODINOW

Physicist and author who wrote books with Stephen Hawking. His latest book is Elastic, Flexible Thinking In A Constantly Changing World.

"Stephen didn't let anything go. We would argue over individual words. For me, the argument wasn't hard, but he would go through a lot of work to present his side. He'd say himself that his best and worst quality was his stubbornness. I don't think he could have gotten through life if he wasn't so stubborn.

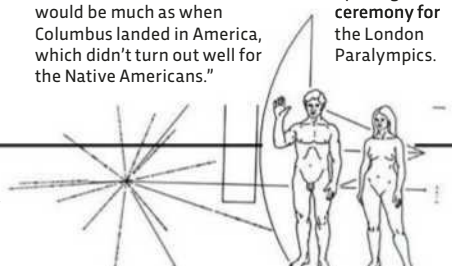
We wrote about physics because it was just so beautiful. I thought everyone would love it, if they could understand what we were talking about. I think Stephen felt the same. I mean, Stephen didn't think *A Brief History Of Time* was clear. He described it as the most bought and least read book of all time. That's why we wrote *A Briefer History Of Time* together.

The movie [*The Theory Of Everything*] was "broadly accurate", as Stephen put it, which people took as an endorsement. But I know Stephen. When he says that, he means it's not necessarily accurate in the details. That was a perfect Stephenism. A detail that bugged me was the moment he gets the idea for Hawking radiation. He struggled with this for months, years. But in the movie he gets the idea staring into a fireplace, seeing some embers explode, and it cuts to everyone clapping, but it doesn't work that way. It comes back his stubbornness."

PHOTOS: GETTY, ALAMY, BBC, NASA

2010

Hawking questions attempts (such as Voyager's golden record) to communicate with putative alien intelligences, saying: "If aliens visit us, the outcome would be much as when Columbus landed in America, which didn't turn out well for the Native Americans."



2012

Hawking provides the narration for the *Enlightenment* segment of the opening ceremony for the London Paralympics.

2014

Eddie Redmayne plays Hawking in a biopic entitled *The Theory Of Everything*. The film is based on a memoir written by his first wife, Jane, called *Travelling To Infinity*.

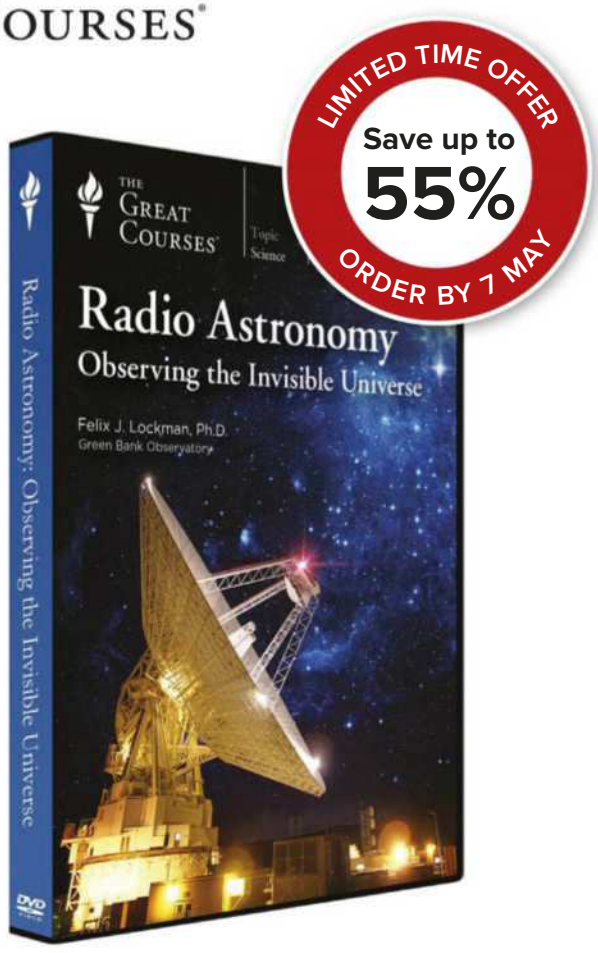
2016

Launches the Stephen Hawking Medal for Science Communication, awarded to artists, entertainers and media figures whose work has helped improve public understanding of science.

2018

On 14 March 2018, Hawking dies at home in Cambridge. He is survived by his three children and three grandchildren.

THE GREAT COURSES®



Pull Back the Curtain on the Unseen Universe

For a few hundred thousand years, we used our eyes as our primary astronomical tool. But all that changed in the 1930s when a young engineer named Karl Jansky detected radiation below the visible part of the spectrum emanating from an astronomical object—and radio astronomy was born.

Radio Astronomy: Observing the Invisible Universe takes you on a thrilling journey through astounding discoveries and a virtual tour of the world's most powerful radio telescopes with Felix J. Lockman, Ph.D., of the Green Bank Observatory as your guide. But perhaps the most astounding of all radio astronomy discoveries is this: The dominant molecular structures in interstellar space are based on carbon. That is not what scientists had expected. We have always labeled these molecules "organic" because life on Earth is carbon based. Now we know the chemistry of the entire Milky Way is organic, not just our home planet, and it is likely that any extraterrestrial galactic life would be related to us, at least on the molecular level. Will we find other organic life forms out there? Radio astronomers don't know. But they're certainly working on it.

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INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

APRIL 2018 EDITED BY HELEN GLENNY

LIGHT UP

Daimler dazzled at the Geneva Motor Show with its new Digital Light technology, which it will roll out in the first half of 2018. The computer-controlled high-definition headlights project information onto the road ahead, including warnings if you're speeding, or if you're travelling too close to the car in front. The lights also tell you when you're drifting out of your lane, warn of low-grip conditions, show you how wide your car is, and point an arrow at any pedestrian who looks in danger of stepping onto the road.

The technology is part of Daimler's 'Intelligent Drive' strategy, and integrates information from the car's sensors and GPS data. It displays that information using the one million micro-reflectors on the surface of each headlight, which will automatically dim to avoid dazzling the drivers of oncoming cars.

The tech doesn't come cheap, so for now it's only featured in the top-model Mercedes-Maybach S-Class. As the system becomes more affordable, it will be included in other cars.

1

2

3

4

5

6

WANTED

1

FISH FOOD

In this self-contained aquaponics kit, waste from the fish is pumped into the planter above the aquarium. Bacteria in the planter turn the waste into nutrients for the plants, and the plants filter the water, which is cycled into the aquarium.

AquaSprouts Garden

$169.99 (£123 approx), aquasprouts.com

2

SURROUND SOUND

This headset includes sensitive microphones that pick up 3D sound in your video recordings. When anyone tunes in to watch your vids, they're treated to an immersive 360° experience that gives the sensation of really being there.

Sennheiser AMBEO Smart Headset

£259.99, sennheiser.com

3

COMMUTE LIKE A KID

With a maximum speed of 20km/h (12mph) and a 25km (15.5-mile) range, the Segway ES1 Ninebot Kickscooter might make you a little happier about your morning commute. It even has cruise control for those longer journeys.

Segway E1 Ninebot Scooter

£449, segway.com

4

SUPER SUB

You know what fishing needs? More robots. The PowerDolphin is a do-it-all underwater drone that will bait and snare fish within 40 metres, film you surfing in 4K, deliver life preservers to struggling swimmers, and map the seabed.

Powervision PowerDolphin

£749, powervision.me

5

DIGITAL DETOX

The Light Phone 2 is designed to be distraction-free – it can only call, send messages, save contacts and be used as an alarm. Developers are now exploring adding maps, music and ride-hailing, at a slight risk of defeating its purpose.

Light Phone 2

$225 (£165 approx), bit.ly/2Dsnsh6

6

HEAR EVERYTHING

Do you keep missing train station announcements because of your music? The Sony Xperia Ear Duo's Dual Listening Technology lets you hear external sounds and conversations even when you're listening to music or on calls.

Sony Xperia Ear Duo

£229, sonymobile.com

7

TAKE FLIGHT

Zapata's new jet-powered hoverboard can reach heights of 3,000m, travel at 140km/h (87mph), and is reportedly being eyed-up by the US military.

Owned by US-based Implant Science, a Department of Homeland Security supplier, Zapata's Flyboard Air (pictured) can manage a brief 6- to 10-minute flight on a full tank of fuel, long enough to travel around four kilometres.

Franky Zapata is the only pilot trained to demonstrate the Flyboard Air, but the company also has the EZ-Fly, a more stable, safer hoverboard. If you fancy it, you could take to the skies too. All you need is some spare time for training, a cool £213,000, and a total disregard for your own safety.

Zapata EZ-Fly

€240,000 (approx £213,000), zapata.com

HEALTH

New eyedrops could spell the end of faffing round with expensive contact lenses and glasses

NANOPARTICLE EYEDROPS COULD REPLACE YOUR CONTACTS

Contacts could soon become obsolete, thanks to a smartphone app, one-second surgery, and some nanoparticle eyedrops.

Researchers from Shaare Zedek Medical Centre and Bar-Ilan University in Israel have used the new 'nanodrops' to correct short- and long-sightedness in pigs and hope to start human clinical trials later this year.

Their invention works in three steps. First, a smartphone app measures the patient's eye refraction. A doctor then projects a laser pattern onto the patient's eye, which creates shallow grooves on the cornea's surface. This takes less than one second. The nanodrops then fill in those shallow grooves. The nanoparticles refract light differently from the liquids in the eye, so applying them in a specific pattern changes the way light passes through the cornea.

Unlike laser eye surgery, the treatment only affects the outer part of the cornea, which means the eyedrops can be applied at home without medical supervision. However, the cornea heals itself over time, so the treatment has to be repeated every few months.

COMPUTING

ARTIFICIAL INTELLIGENCE TRIAGES EMERGENCY CALLS

Artificial intelligence is helping emergency dispatchers identify heart attacks faster and more accurately. Named Corti, this new program's deep neural networks analyse words, tone of voice, breathing patterns and background noise during an emergency call. It guides the dispatcher through the call, predicts the seriousness of a patient's situation, and alerts the dispatcher to issues like cardiac arrests.

Corti was trialled at Emergency Medical Services Copenhagen, where dispatchers can usually identify cardiac arrests 73 per cent of the time. When dispatchers were aided by Corti, 95 per cent of cardiac arrests were identified correctly. Corti makes decisions based on thousands of other recorded emergency calls that it has already analysed. Every time a new emergency call is processed, its machine learning technology incorporates the new information and improves its own accuracy.

"Our dispatchers do an incredible job under high pressure and in circumstances where the person on the line is often scared or experiencing panic-inducing symptoms," said Freddy Lippert, CEO at Emergency Medical Services Copenhagen. "During the time that we have used Corti to augment our existing service, we have seen how the platform can support dispatchers by expediting accurate diagnoses. There are people in Copenhagen today for whom Corti has proved a real lifesaver."

Artificial intelligence can help emergency dispatchers improve diagnoses

PHOTOS: GETTY, ALAMY

TECH BYTES

INTRODUCING FLIPPY

Pasadena's CaliBurger employed its first burger-flipping robot, creatively named Flippy. Flippy covered the busy 11am 'til 2pm lunch shift, but was withdrawn after just one day.

DRIVERLESS OXFORD

Driverless cars have taken to the streets of Oxford, in a £6.8m trial. Oxbotica, the company running the trial, is testing the cars on Oxford's narrow streets, and hopes they'll soon be able to drive themselves to London.

SNOWBOTS

Just Eat's robots successfully navigated the snow to deliver takeaways to customers in Milton Keynes during Storm Emma. The robots have completed over 1,000 deliveries since their 2016 launch, and have now proven themselves in tough weather.

ROAD TO THE FUTURE

At the Geneva International Motor Show, car manufacturers showcase the most impressive developments in luxury, practicality, speed and sustainability. These four cars show us where the future of motoring is headed…

THE NEED FOR SPEED

The race to break the 300mph (482km/h) barrier is heating up, with Hennessey producing the latest candidate. Company founder John Hennessey says that the sunshine-yellow Venom F5 is capable of taking down what's regarded as one of the last achievable road records. He claims that the Venom – with its 1,600 horsepower, twin turbo V8 engine – can push all the way to 301mph. Whatever happens, the Venom F5 proves that our fascination with speed isn't going away.

DIESEL ISN'T DEAD

With increased diesel taxes and bans being introduced to cities all over Europe, it's no surprise that some car manufacturers are ending production of diesel vehicles. But Mercedes rocked up at the Geneva International Motor Show and claimed that diesel isn't dead yet. Fans claim the Mercedes C300de plug-in diesel hybrid marries the best of diesel with low urban emissions, but we'll have to wait and see whether diesel hybrids will have a place among the upcoming diesel regulations.

SUBSCRIBE AND DRIVE

With the hybrid Polestar 1, Volvo's ditching the traditional own-your-own-car model and replacing it with an all-inclusive two- or three-year subscription that covers hassles like insurance and maintenance. The Polestar 1 has a nifty 'phone-as-key' system that allows you to open the car using an app and authorise access to others. With simple sign-ups and the ability to avoid depreciation costs, the subscription model might be the way of the future.

TAKING ON TESLA

The Geneva Motor Show was full of challengers to Tesla's luxury electric vehicle dominance, but the Jaguar I-Pace outpaced the rest. It's Jaguar's first fully electric vehicle and matches up with Tesla's entry-level Model X, with similar specs at a lower price. Porsche, Audi and BMW all showed off their upcoming electric models, but Hyundai summed it up best with a giant billboard for its new Kona Electric that read: "Your turn, Elon".

PHOTOS: NEWSPRESS

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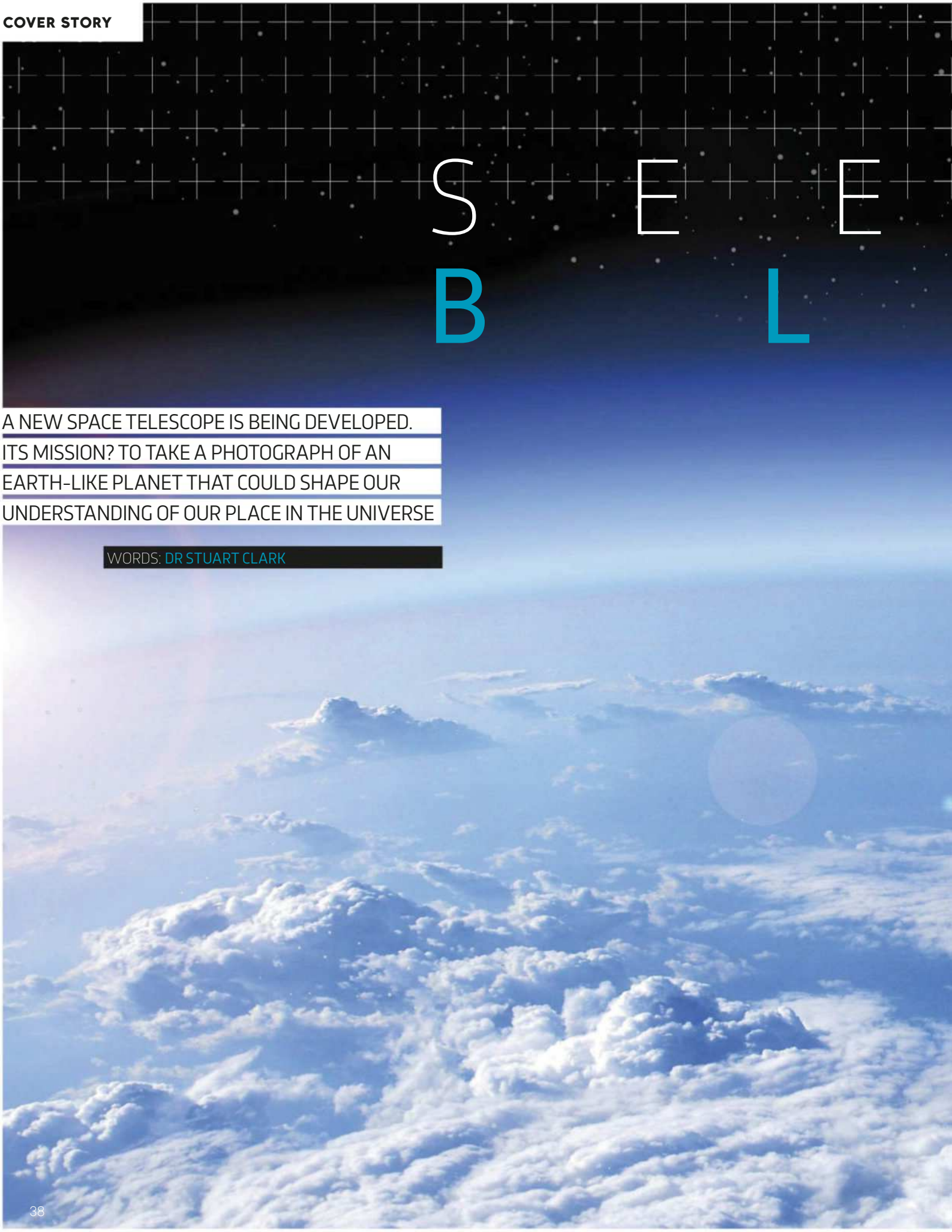
A NEW SPACE TELESCOPE IS BEING DEVELOPED. ITS MISSION? TO TAKE A PHOTOGRAPH OF AN EARTH-LIKE PLANET THAT COULD SHAPE OUR UNDERSTANDING OF OUR PLACE IN THE UNIVERSE

WORDS: DR STUART CLARK

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BBC FOUR
For space news, don't miss monthly episodes of *The Sky At Night*
April: Mars
May: Gaia mission
June: Juno mission
bit.ly/sky_at_night

PHOTO: GETTY

CHRISTMAS, 1968. THREE MEN WERE IN ORBIT AROUND THE MOON, AS FAR AWAY FROM EARTH AS ANYONE HAD EVER GONE. THEY THOUGHT THE MAGNIFICENT DESOLATION OF THE LUNAR LANDSCAPE WAS THE MOST STUNNING THING THEY WERE GOING TO SEE DURING THEIR MISSION. BUT THEY WERE WRONG.

On their fourth orbit, astronaut Bill Anders saw Earth rise above the Moon's horizon. He photographed the moment and in doing so gave the world one of the most iconic images of the space age. This picture of the seemingly fragile blue planet Earth subsequently became a symbol to represent both the environmental movement and the wonders of space exploration. Now, a group of privately funded astronomers and engineers want to recreate that act by taking a new picture of another blue planet – one around another star.

BLUE SKY THINKING

Dubbed Project Blue, the mission aims to build and launch a space telescope with a single goal in mind: to image any planets in the habitable zones of the nearest Sun-like stars. If such planets were Earth-sized with oceans and atmospheres, then they could even "see Blue", Project Blue's term for finding a potentially habitable planet.

The mission is the brainchild of the BoldlyGo Institute. This not-for-profit organisation was founded by Dr Jon Morse, a former NASA scientist and White House science advisor, to investigate highly compelling scientific questions using private money from donors and crowd-funding initiatives. And there are few questions more compelling than whether there are other Earth-like planets around other stars.

The quest to find Earth-analogues, as these planets are known, began in earnest in 1995 when a pair of Swiss astronomers discovered 51 Pegasi b – the first extrasolar planet (or exoplanet) to be found around a Sun-like star. It was the size of Jupiter and not at all Earth-like, but it proved that planets were now in reach of our technological abilities.

In the decades since, almost 4,000 other exoplanets have been detected but hardly any have had their picture taken. The trouble is that planets do not generate any of their own light and instead simply reflect their star's light. This makes them more than a billion times fainter than their parent star. Telescopes to date have been able to catch a few glimpses of large planets, but planets the size of Earth have remained impossible to image. Instead, astronomers have used indirect observations to infer the existence of the exoplanets.

Most of the exoplanets found so far were detected using NASA's Kepler Space Telescope. Kepler tracked a star's brightness, looking for the dip caused when a planet crossed in front of it. Its instruments were

"ALTHOUGH SOME EXOPLANETS GRABBED HEADLINES AROUND THE WORLD, TO DATE WE HAVE NOT FOUND A TRUE EARTH-TWIN"

EARTHRISE
Taken on Christmas Eve by the crew of Apollo 8, Earthrise was the first time a human had seen Earth rise from behind the horizon of the Moon. A subsequent mission, Apollo 10, took a video of the Earthrise. For more iconic images, turn to pages 44-46

precise enough that it could see smaller rocky (also called terrestrial) planets but none of them have proved to be a twin to Earth. Although some grabbed headlines around the world for being similar, to date we have not found a true Earth-twin in the sense that it is an Earth-sized world in an orbit the size of Earth's around a Sun-like star.

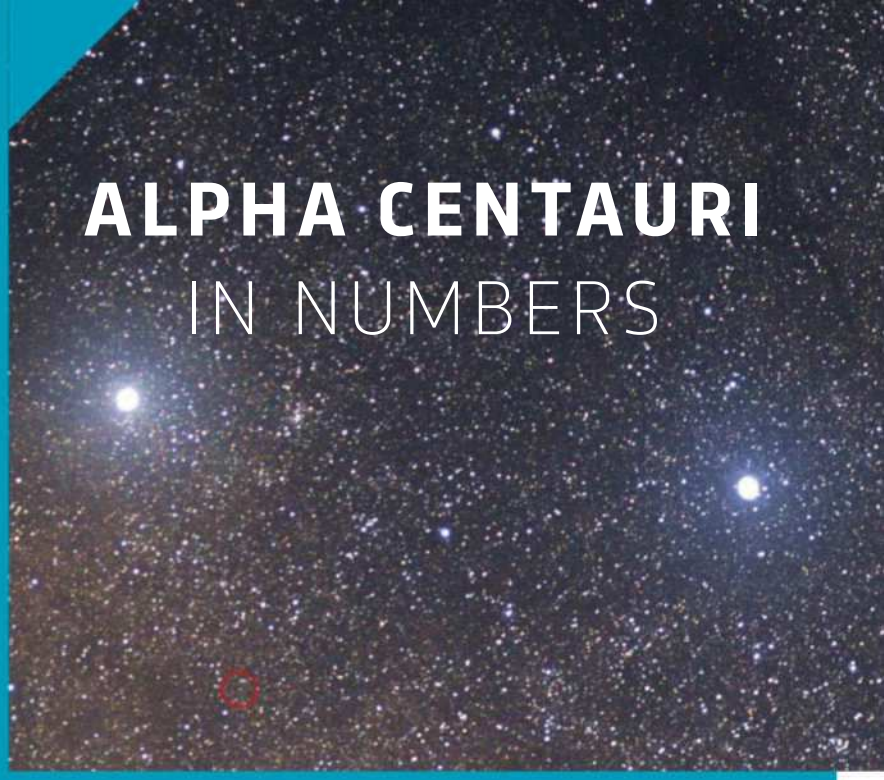
As luck would have it though, the nearest star system to the Sun contains two stars that could be extremely rewarding places to look.

PLANET HUNT

Alpha Centauri is made up of three stars in mutual orbit around each other. One of these, known as Proxima Centauri, is a red dwarf star and therefore considerably smaller and cooler than the Sun. Of the others, Alpha Centauri B is similar to the Sun and Alpha Centauri A is virtually identical. These are the stars that Project Blue will target.

Existing studies of these two stars show that large planets like Jupiter are not present. So if there are planets there, all they can be are ▶

ALPHA CENTAURI IN NUMBERS



Alpha Centauri A (left) and B (right) appear as a single bright star to the naked eye. They are not visible from the UK, and can only been seen in the southern hemisphere. Proxima Centauri is marked with a red circle

4.37
The distance, in light-years, to Alpha Centauri A and B. Proxima Centauri is a little closer, at 4.24 light-years.

80
The number of years it takes Alpha Centauri A and B to orbit their common centre of gravity.

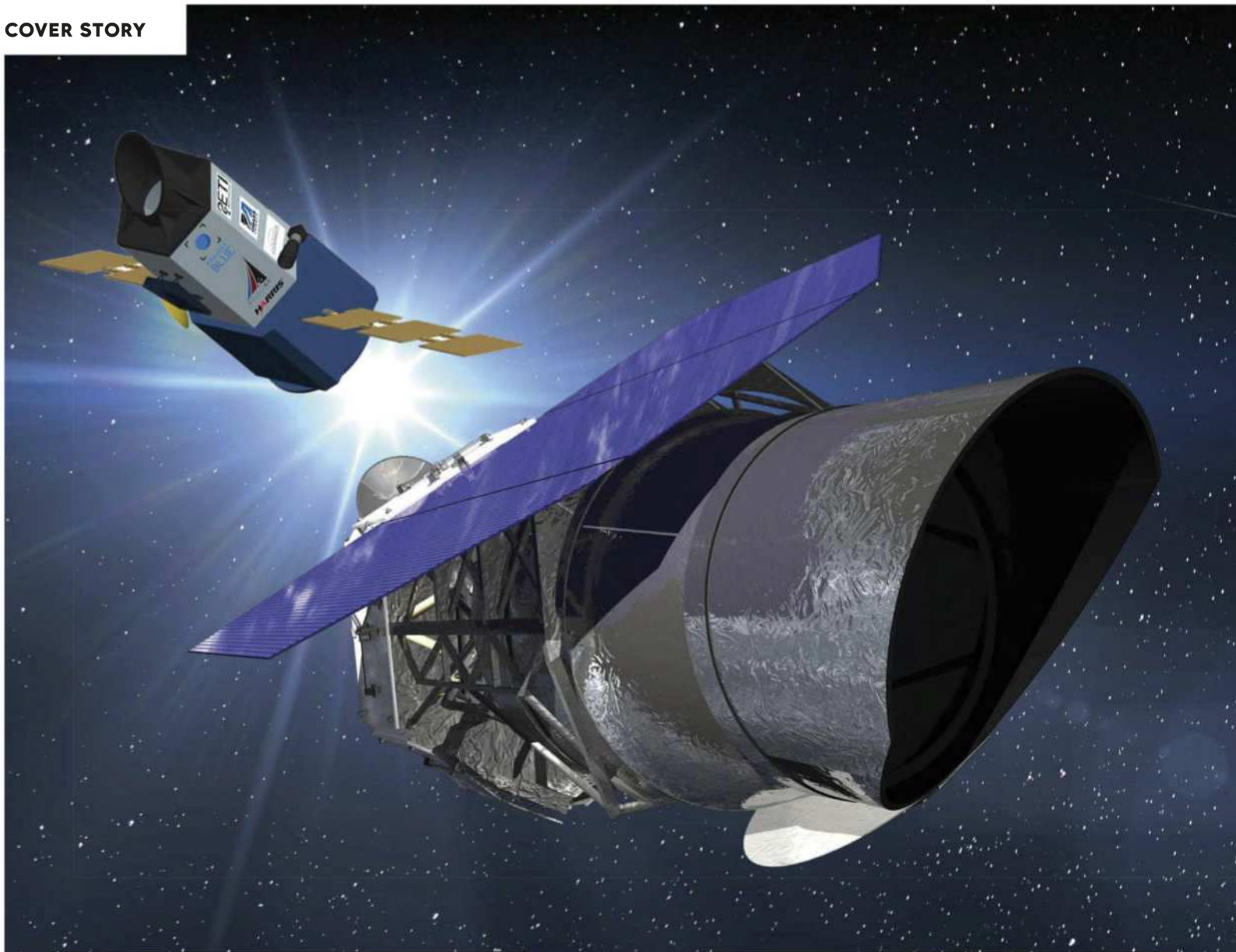
1.1
The solar mass of Alpha Centauri A. (One solar mass is the same as our Sun's mass.) This is the most similar star to our Sun in the Alpha Centauri system.

0.9
The solar mass of Alpha Centauri B. It is less than half as bright as the Sun.

25,000
Over this number of years, the Alpha Centauri system will double in brightness as it moves closer to us.

1915
The year that Proxima Centauri was discovered by Scottish astronomer Robert Innes. The star cannot be seen with the naked eye.

30°C
The temperature of Proxima b, Proxima Centauri's planet, if it has an atmosphere. This is warm enough for liquid water to exist. Without an atmosphere, temperatures may be as low as -39°C.



Earth-sized worlds in Earth-like orbits. "That's what we are going to test," says Morse.

The project proposes a small space telescope. Its mirror is just 0.5 metres in diameter, which makes it about half the size of Kepler. Yet this should be big enough for Project Blue to take direct pictures of any planets as they move around their star because the spacecraft will use an instrument called a coronagraph. It will block out the light from the central star, allowing the much fainter planet to be seen.

Don't expect anything spectacular, though. Any planet will appear as nothing more than a single pixel of light, similar to the image of Earth captured in 1990 by the Voyager 1 spacecraft from a distance of four billion miles. Despite its lack of aesthetic beauty, it would allow scientists access to unprecedented information about the planet.

"Monitoring the brightness and the colour of planets over time is what allows you to make maps of the surface," says Dr Margaret Turnbull of the Carl Sagan Center for Research at The SETI Institute, California, and a member of the Project Blue team. "Are there oceans? Are there continents? Are there cloud patterns? Weather patterns? Seasons? If there are, all of those things should be reflected – literally – in the colour data and in the brightness of the planet over time."

ABOVE: **Project Blue (left) will be launched into low-Earth orbit and will photograph planets in the Alpha Centauri system. It will use a lot of technology being developed for NASA's much larger WFIRST mission (right)**

Earth, for example, looks bluer when we are looking at an ocean than at a continent, and it is brighter when we are looking at Antarctica.

TELESCOPE TECH

The simplicity with which the mission can be stated belies the technical challenge. No one has yet flown a coronagraph designed for taking pictures of Earth-like planets. Project Blue is working closely with NASA, which is planning a much larger mission called WFIRST (the Wide-Field Infrared Survey Telescope). It is designed to have the sensitivity of the Hubble Space Telescope but with a field of view 100 times the size and will include a coronagraph that Turnbull has been working on. Project Blue will use a lot of the ideas and technology being developed for WFIRST to provide an orbital test of how to use such an instrument to detect planets. This is why it is so important to devote the whole mission to exploring just one star system.

"Having continuous coverage is a big deal," says Turnbull. "Staring at the same space for months

HOW IT WORKS: CORONAGRAPH

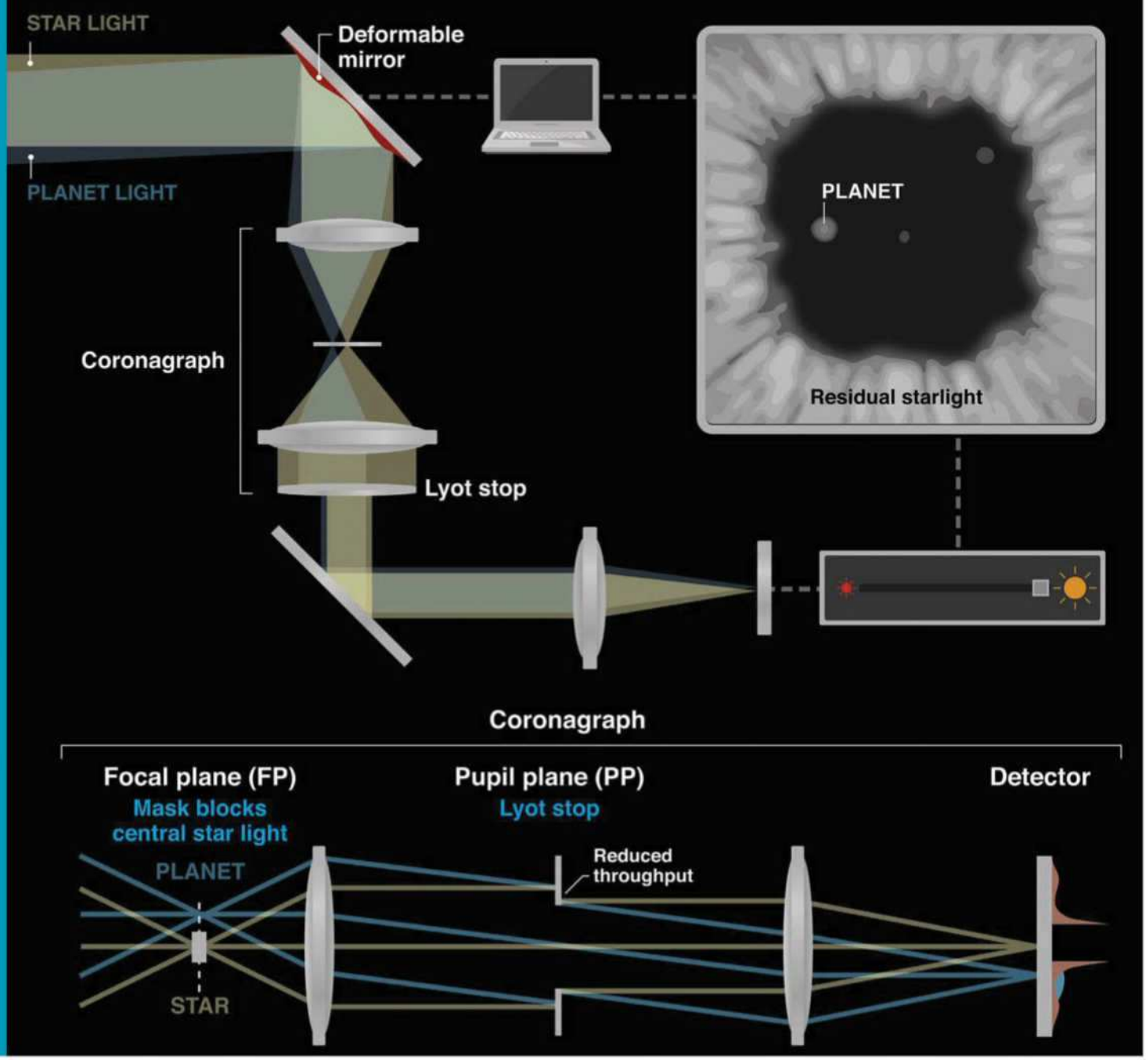
Project Blue will use a device called a coronagraph to take pictures of any planets around Alpha Centauri. A coronagraph is a device that blocks the bright light from a central object but allows the faint light from its surroundings to enter the telescope.

It was invented in the 1930s by French astronomer Bernard Lyot. He wanted to study the Sun's faint outer atmosphere which became visible only during a total eclipse when the Moon blocked the Sun's bright disc, so he designed and built a device that could mimic the action of the Moon and create an artificial eclipse inside his telescope. Since the Sun's outer atmosphere is called the corona, Lyot's device was christened a coronagraph.

Looking for exoplanets is another good example of wanting to see something faint next to something bright. Planets do not generate their own light, instead they simply reflect that given out by their parent stars. It has been compared to trying to see a firefly on the rim of a searchlight.

In space, coronagraphs have principally been used to view the Sun with spacecraft such NASA-ESA's Solar and Heliospheric Observatory (SOHO) mission. The Hubble Space Telescope did include a coronagraph in its Near Infrared Camera and Multi-Object Spectrometer (NICMOS). In 2011, it was used by astronomers to take an image of the four exoplanets around star HR 8799. Taking repeated images of planets allows their motion around their star to be seen.

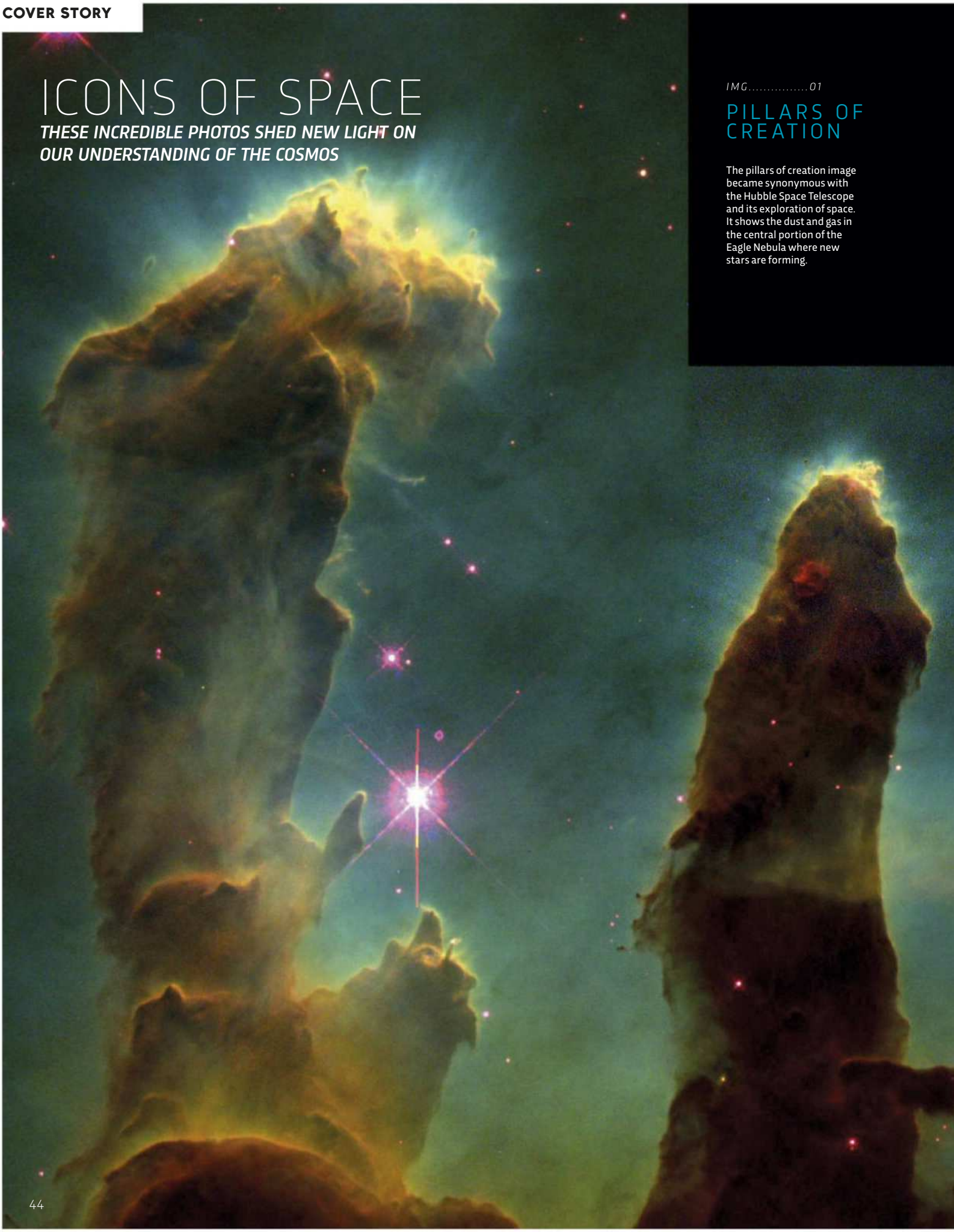
The NASA James Webb Space Telescope, which will launch next year will also include a coronagraph in it Near Infrared Camera (NIRCam).



PHOTOS: BOLDLYGO, NASA ILLUSTRATION: ACUTE GRAPHICS

ICONS OF SPACE

THESE INCREDIBLE PHOTOS SHED NEW LIGHT ON OUR UNDERSTANDING OF THE COSMOS



IMG.....01

PILLARS OF CREATION

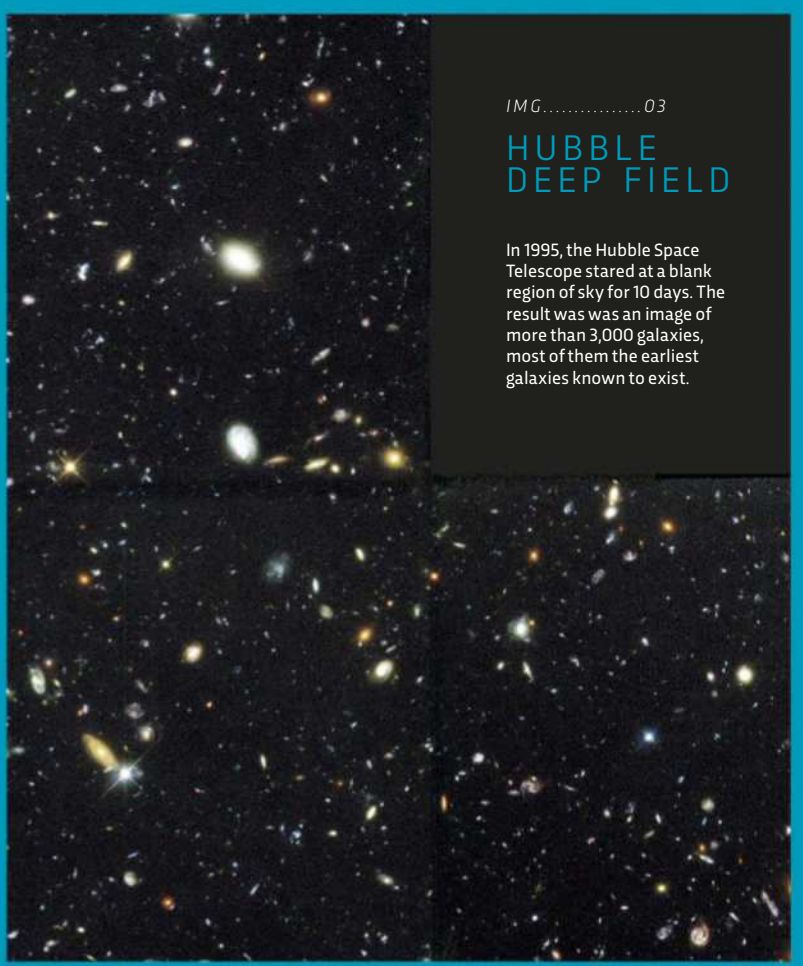
The pillars of creation image became synonymous with the Hubble Space Telescope and its exploration of space. It shows the dust and gas in the central portion of the Eagle Nebula where new stars are forming.

IMG.....02

ROSETTA'S COMET

Comet 67P/Churyumov-Gerasimenko, a leftover from the formation of the planets, became a symbol of success for the European Space Agency (ESA). ESA used the Rosetta spacecraft to explore the comet, and landed with Philae in 2014.

PHOTOS: NASA X2, ALAMY



IMG.....03

HUBBLE DEEP FIELD

In 1995, the Hubble Space Telescope stared at a blank region of sky for 10 days. The result was was an image of more than 3,000 galaxies, most of them the earliest galaxies known to exist.

IMG.....04

BLUE MARBLE

Another Apollo image of the Earth, this shot shows Africa and Antarctica prominently. It was taken on 7 December 1972 just over five hours into the flight of Apollo 17, as the mission was travelling to the Moon.

IMG.....05

PALE BLUE DOT

At first sight, the pale blue dot image may seem underwhelming, but that's what gives it its power. Our entire planet is contained in a single blue pixel, as seen from Voyager 1 at a distance of four billion miles.

"PROJECT BLUE IS PURE EXPLORATION. WE ARE GOING INTO THE UNKNOWN"

Dr Jon Morse, founder of the BoldlyGo Institute that heads up Project Blue

PHOTOS: NASA X2, ALAMY, BOLDLYGO X2

Inspired by the LSST (below left) and the Keck Observatory (left), which both received money from private investors, Dr Jon Morse set up the BoldlyGo Institute to attract funding for Project Blue and other missions

or years at a time, then you can be sure you are going to detect any planet within that orbital range."

It seems such an obvious thing to do that the question of why NASA isn't already planning its own test mission is a natural one. As Morse explains, it all comes down to money. From 2007 to 2011, he was NASA's director of the astrophysics division and towards the end of that tenure, he noticed a worrying trend. "If you look at the budget history of astrophysics at NASA, there is a big dip in the early 2010s," he says.

This was clearly going to impact the number of missions the division could build. Yet at the same time, ground-based observatories such as the Keck telescopes and the forthcoming Large Synoptic Survey Telescope (LSST) were forging ahead, thanks to money from private investors. Both of those telescopes are general-purpose observatories that perform a wide variety of observations. Nevertheless, the sums of money involved opened Morse's eyes.

"Those projects are on a budget level that is on a par with sophisticated satellites," he says. So, he set up the BoldlyGo Institute as a vehicle for attracting private money to launch more space missions.

Project Blue fits perfectly into that vision. Morse hopes that the spacecraft can be built for around $50m and launched some time in the early 2020s for around $10m. If he pulls it off, the cost alone could be a game changer. NASA's first planet finder, Kepler, cost $550m. The launch costs alone for its next planet finder, The Transiting Exoplanet Survey Satellite (TESS) mission, which is due to launch in April, are $87m. Yet according to the people behind Project Blue, the mission's potential impact extends beyond mere budgets. It even extends beyond doing science.

AGE OF EXPLORATION

Project Blue speaks to what it means to be human, to that part of us that is restlessly curious to explore. "Project Blue is pure exploration. We are going into the unknown. We are looking at what is there," says Turnbull. "I love the idea of simply exploring and going to see what is there."

Morse echoes these sentiments. "It looks to the far future," he says. "If we ever go to the stars, we will go to the closest place first." And that means the Alpha Centauri system.

Project Blue is literally looking for the targets that our great-great-etc. grandchildren may one day see with their own eyes.

Dr Stuart Clark is an astrophysicist and science writer. His latest book is *The Search For Earth's Twin* (£20, Quercus). stuartclark.com

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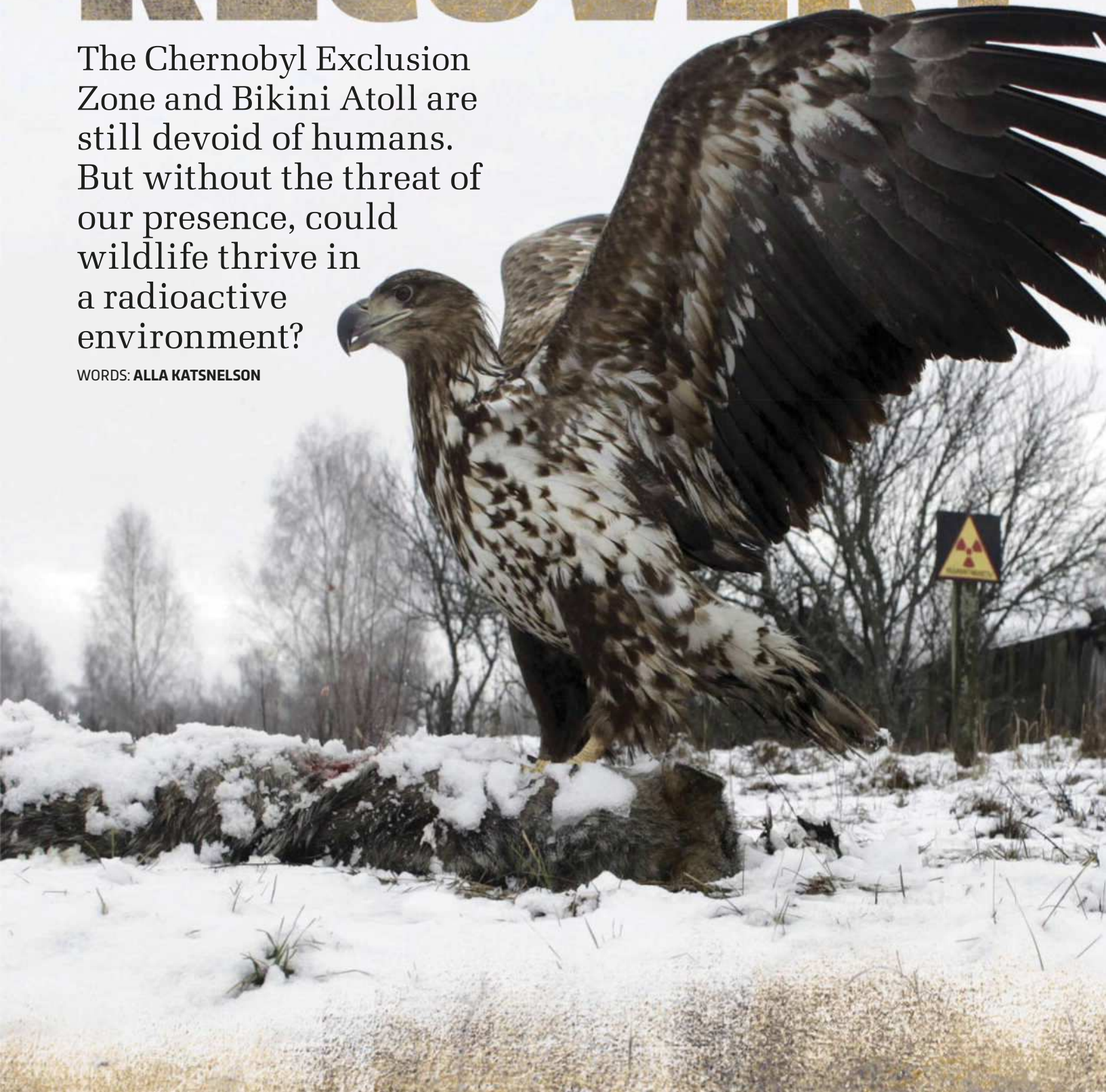
THE ROAD TO RECOVERY

The Chernobyl Exclusion Zone and Bikini Atoll are still devoid of humans. But without the threat of our presence, could wildlife thrive in a radioactive environment?

WORDS: **ALLA KATSNELSON**



A white-tailed eagle lands on a wolf's carcass inside the 30km exclusion zone surrounding the Chernobyl nuclear power plant

PHOTOS: REUTERS

Early this year, the Doomsday Clock ticked forwards to two minutes to apocalypse – the closest it's been since 1953 when the US and the Soviet Union tested hydrogen bombs. *The Bulletin Of The Atomic Scientists* opted to move the clock forwards due to growing concerns about potential nuclear war, whether such events be borne of strife between the US and North Korea, Pakistan and India, or some other crisis point.

In the past, we have seen the immediate effects of radiation, through nuclear bombs or power station failures. By visiting radioactive sites like these, enterprising scientists can find out about the long-term impact of radiation on the environment, so we know what to expect in the event that someone pushes the big red button.

GOING NUCLEAR

One place that might offer some clues is Bikini Atoll, a ring-shaped coral reef located in the Marshall Islands. In 1946, the US evacuated Bikini's residents, then spent 12 years testing its nuclear firepower by detonating 23 nuclear bombs there, including one that packed 1,000 times the power of the one that devastated Hiroshima and was the largest nuclear device that the US ever exploded. It's a place, you might think, that'd be completely devoid of life to this day.

But in 2016, Steve Palumbi, professor of marine sciences at Stanford University in California, visited Bikini to document the marine life. He first got interested in Bikini while researching his book *The Extreme Life Of The Sea*. He learned that the age of organisms could be determined by measuring their artificial carbon-14 levels caused by hydrogen bomb tests in the middle of the last century. So when he was invited by the US television station PBS to do a documentary series called *The Big Pacific*, he told the producers that he wanted to go to Bikini Atoll.

Rather than finding it barren, he discovered a diverse array of species including corals, fish, sharks and crabs thriving in the atoll's waters. Undoubtedly, the complete absence of humans for more than seven decades has helped create an undisturbed territory in which wildlife could flourish.

"When you started looking at the reports and hints, we were expecting to see some recovery – we just had no idea how extensive," he says. And according to his team's observations, the organisms appeared ▶

quite normal, with no obvious mutant characteristics. "There are a lot of strange things there – like coconuts the size and shape of zucchinis [courgettes] on the trees," he says. "But can you really pin these things on radiation? It's not all that clear."

Ukraine provides another example of the surprising ways that life can recover after exposure to radiation. Early on 26 April 1986, reactor 4 of the Chernobyl nuclear power plant exploded, due to a fatal combination of engineering glitch and human error. Between the explosion and the subsequent fire, which raged for 10 days, the accident spewed about 400 times more radioactive material into the atmosphere than what was released by the Hiroshima and Nagasaki bombs combined. Ultimately, officials evacuated some 330,000 people from the region and established a so-called Chernobyl Exclusion Zone that today covers about 4,200km^2, graded by four levels of contamination.

"We don't really know very much about what went on right after the disaster at Chernobyl, other than the fact that everything was wiped out for many miles – everything from trees, to mammals, to insects," says Prof Timothy Mousseau, a biologist at the University of South Carolina.

ROAD TO RECOVERY

In the decades since, researchers have watched the region closely for signs of recovery. Prof Jim Smith, an environmental scientist at the University of Portsmouth, has worked with scientists from Belarus to monitor some of the mammals that live in the zone, such as wild boar, elk and wolves. Surprisingly, he says, populations seem to have bounced back, both in terms of abundance and diversity. As Smith explains, contamination within the zone is uneven: about 1 per cent of the region consists of areas like the infamous Red Forest, with its off-the-chart radiation levels, while much lower levels exist elsewhere. But even in the hotspots, he and his collaborators have seen no decrease in population numbers of big mammals (except wolves) compared to nearby radiation-free nature reserves.

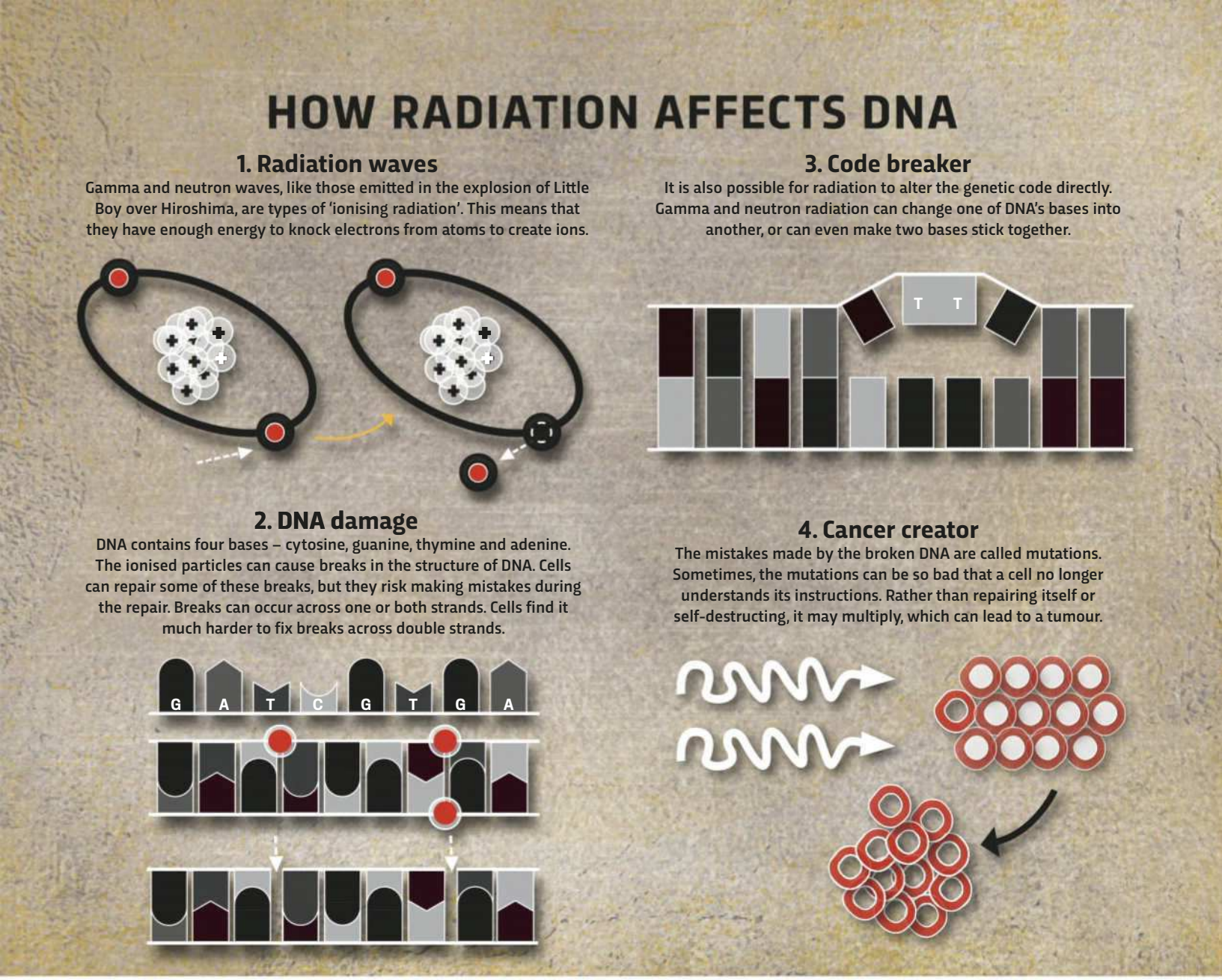
"BIKINI ATOLL LOOKS FINE, BUT THERE'S AN INVISIBLE MENACE THERE"

So if wildlife has flourished in the decades after a nuclear event, does it suggest that these regions have rapidly recovered? Absolutely not, says Palumbi about Bikini. "It looks fine, but there's an invisible menace there," he explains. In the early 1970s, some people who had lived at Bikini Atoll before the bomb tests were told they could return, only to be re-evacuated a few years later due to lingering unsafe radiation levels. "If you do exactly what you're not supposed to do and follow the signals [of the radiation counter] to where it gets stronger, you end up at the water well [a freshwater source]," he says.

A 2016 study that re-examined radiation levels at the Marshall Islands concluded that Bikini's contamination is higher than previously thought, although at other islands it seems to have dissipated. Researchers concluded that figuring out whether

ABOVE: **All of Bikini's coconut palms were destroyed after the nuclear tests. The army replanted them in a perfect grid shape**

INSET ABOVE: **Coconuts are one of the most contaminated food sources on Bikini**



the islands had become habitable would involve determining the radioactive dose from ingesting food farmed or caught there. "Every day there were moments that told you something was very wrong about the place, like when the boat's navigation system screamed we had run aground because it was using maps from 1935, and where we were anchored – in 49 metres of water – had been an island back then," says Palumbi.

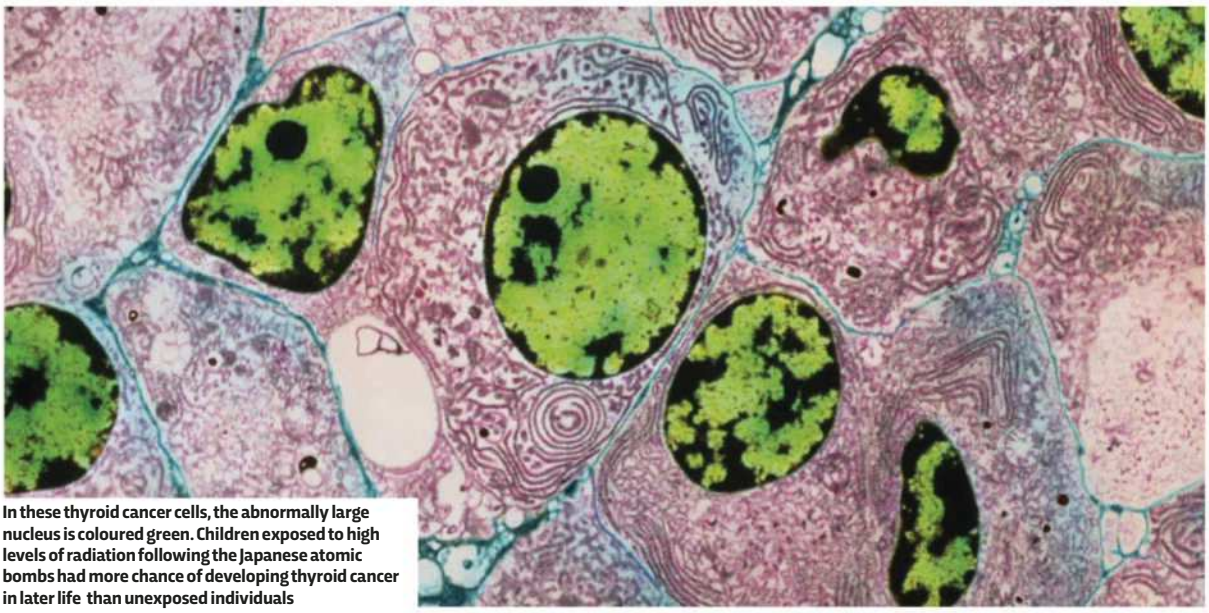
The story in Chernobyl is perhaps even more complicated. Mousseau points out that, for wildlife, the presence of humans is in some ways worse than large doses of radioactivity. This is because humans encroach on the habitats of many animals through settlement, hunting and agriculture. That's why his team studies organisms like small rodents, insects, birds and trees. As these are less influenced by the presence or absence of humans, it gives the scientists more opportunity to home in on the effects of radioactive contaminants, he says.

Mousseau and his colleagues do see problems on both the population and the individual level that they believe stem from elevated radiation levels. For example, they reported a heightened incidence of cataracts and generally smaller brains in birds and small mammals at Chernobyl. In radiation hotspots, 40 per cent of birds in some years were completely sterile, they found. What's more, while they observed wolves and some other animals thriving, unlike Smith's group they reported a lower abundance of insects, birds and mammals in highly radioactive regions, as well as reduced rates of growth in pine trees. They found that leaf litter was thicker in areas with high levels of contamination, which suggests that numbers of decomposers – like bacteria and fungi – are reduced. These organisms carry out an essential role in breaking down organic matter to release its carbon and nitrogen. In fact, the Red Forest itself does not seem to be decaying properly, despite having died off following the explosion more than 30 years ago.

HOPE FOR HUMANS

How all this translates to human health is far from clear. The more complex an organism is – and humans are relatively complex – the more susceptible to radioactivity it is thought to be. But the main reason places like Bikini Atoll and Chernobyl are deemed too dangerous for us is not down to some physiological ●

PHOTOS: ROBERT HARDING X2



In these thyroid cancer cells, the abnormally large nucleus is coloured green. Children exposed to high levels of radiation following the Japanese atomic bombs had more chance of developing thyroid cancer in later life than unexposed individuals

differences between humans and other animals, but because the threshold of risk is set much lower for us than for wildlife. "It comes down to a political and sociological discussion – not a scientific one," Smith says. He believes that the recent research suggests that in reality, the risk in much of the region around Chernobyl now is not very high. "Organisms are used to mutation, it's part of life," he says.

In truth, scientists know little about how chronic exposure to low-level radiation affects the body. One of the main planks for understanding the link between radiation exposure and cancer is the so-called Life Span Study, in which 94,000 survivors of the bombing of Hiroshima and Nagasaki, 27,000 unexposed individuals, and their children, have been monitored since 1950. But even there, the effects are less significant than most people think, Smith says. Mousseau, however, argues that endpoints other than cancer, like number of cataracts, head size or immune disorders, reveal a more nuanced picture.

But Palumbi thinks that data from Bikini Atoll could help us fill that knowledge gap. He plans to look at mutation rates in organisms such as corals, which live a long time, and coconut crabs, which regularly eat the most contaminated thing on the island – coconuts – to probe the effect of low-dose exposure on a genomic level. Mousseau, meanwhile, hopes to pursue in-depth genomic and other types of molecular studies in people from near Chernobyl.

MODERN NUKES

It's hard to say how all these variables contribute to the picture of what might happen in the case of an exchange of nuclear bombs today. The biggest concern, experts agree, would be immediate. The most devastating impact of the bombs dropped on

WHY CAN PEOPLE LIVE IN HIROSHIMA AND NAGASAKI BUT NOT THE CHERNOBYL EXCLUSION ZONE?

Today, Hiroshima and Nagasaki are thriving cities inhabited by a total of 1.6 million people, and the background levels of radiation there are no different from elsewhere in the world. Meanwhile, scientists estimate that many areas within the immediate vicinity of the Chernobyl nuclear power plant, most within a 10km area, may be uninhabitable for hundreds to thousands of years. The main reason for the difference in outcomes is that Little Boy and Fat Man, the bombs that hit Hiroshima and Nagasaki, exploded at heights of around 450 to 600 metres, allowing the radioactivity to disperse soon after. Meanwhile, the bulk of the massive release of radioactive material in Chernobyl occurred at ground level. Another difference was the efficiency of fission reaction in the two bombs. Researchers estimate that just 1 per cent of the uranium carried by Little Boy and plutonium carried by Fat Man actually detonated — only about 0.9kg. On the other hand, some 190 tonnes of fuel are thought to have been vaporised in the Chernobyl accident.

PHOTOS: SCIENCE PHOTO LIBRARY, GETTY, SHUTTERSTOCK

ABOVE: **According to some scientists, humans have more of an effect on large animals than radiation does**

"THE BOMBS DROPPED ON NAGASAKI AND HIROSHIMA WERE ITSY-BITSY TINY BOMBS COMPARED TO THE BOMBS THAT WE HAVE NOW"

Hiroshima and Nagasaki was the blast and acute aftermath: estimates suggest some 135,000 and 70,000 people died, respectively, with half of the deaths occurring on the day of the blasts and the rest of the victims experiencing horrific effects over the weeks and months afterwards.

Experts caution that the impact would likely be exponentially larger for any bomb dropped today. "The bombs dropped on Nagasaki and Hiroshima were itsy-bitsy tiny atomic bombs compared to the bombs that we have now," says Mousseau. Today's bombs are about 1,000 times more powerful, and the reactions powering them will be more efficient.

Depending on how many bombs were dropped, and how big they were, nuclear fallout from the explosion would add further contamination in the days and weeks after an explosion. In 1983, the physicist Carl Sagan proposed the controversial notion that if a nuclear explosion tossed enough soot and dust into the air, it could absorb a significant amount of the Sun's rays, causing a nuclear winter. Using the same models that scientists use to predict the long-term effects of climate change, Prof Alan Robock, an environmental scientist at Rutgers University in New Jersey, has calculated that a regional nuclear war could lead to a massive drop in agricultural capacity, a reduction in temperature and precipitation, and an increase in UV irradiation caused by the destruction of the ozone layer. "Global warming would not be one of the things we'd ever worry about again," says Mousseau.

These are just models, of course, but could it happen? It's best that we never find out.

Alla Katsnelson is a freelance writer and editor who specialises in science, health and social issues.

THE ROBOCOPS ARE HERE

AS ROBOTIC POLICE HEAD OUT ON THE STREET OF DUBAI, WE LOOK AT THE TECHNOLOGY THAT'S SET TO REVOLUTIONISE LAW AND ORDER

Words: *Hayley Bennett*

PHOTO: GETTY

1. ROBO ROZZERS

Visitors to Dubai's busy shopping arcades may be surprised to find themselves under the protection of a humanoid police robot. Though it has no mouth, the expressionless bot (see previous page) communicates in Arabic and English, and helps tourists navigate the city, as well as connecting them directly with police services via a touchscreen.

Dubai's answer to RoboCop dresses and salutes like a police officer but is actually from an existing family of robots known as REEM, built and programmed by the Barcelona-based company PAL Robotics. "Citizens can use the robot to contact the Dubai police call centres, speaking through the integrated microphones, and accessing other police-related services such as paying traffic fines. The robot can also report any incidents to a command control centre," a source at PAL tells us.

REEM robots had already spent a number of years working at public events, so it was just a case of customising its software to include police functions, PAL says. The police version has face recognition software, meaning it could potentially catch a criminal by making comparisons with the police database. PAL hopes that the robots will become more accepted as people get used to seeing them around, and we might see them filling roles in healthcare and hospitality in the not-so-distant future.

PAL would not confirm whether it had any further robots on order for Dubai police, or if it would be upgrading the current model. However, Saif Salem Juma Ali Alkaabi at the Dubai police told us that "the numbers of robots will increase for sure". Its Smart Services department previously set a target of replacing a quarter of its on-patrol officers with robots by 2030. The Dubai government has also announced plans for a new model that makes the current officer look like little more than a glorified tourist information point. RoboCop 2.0 will, apparently, be able to run at 80km/h (50mph), controlled by an onboard human.

"Dubai, it seems, is on a mission to dehumanise its police services. The city's streets will be patrolled by the OR-3 autonomous police car"

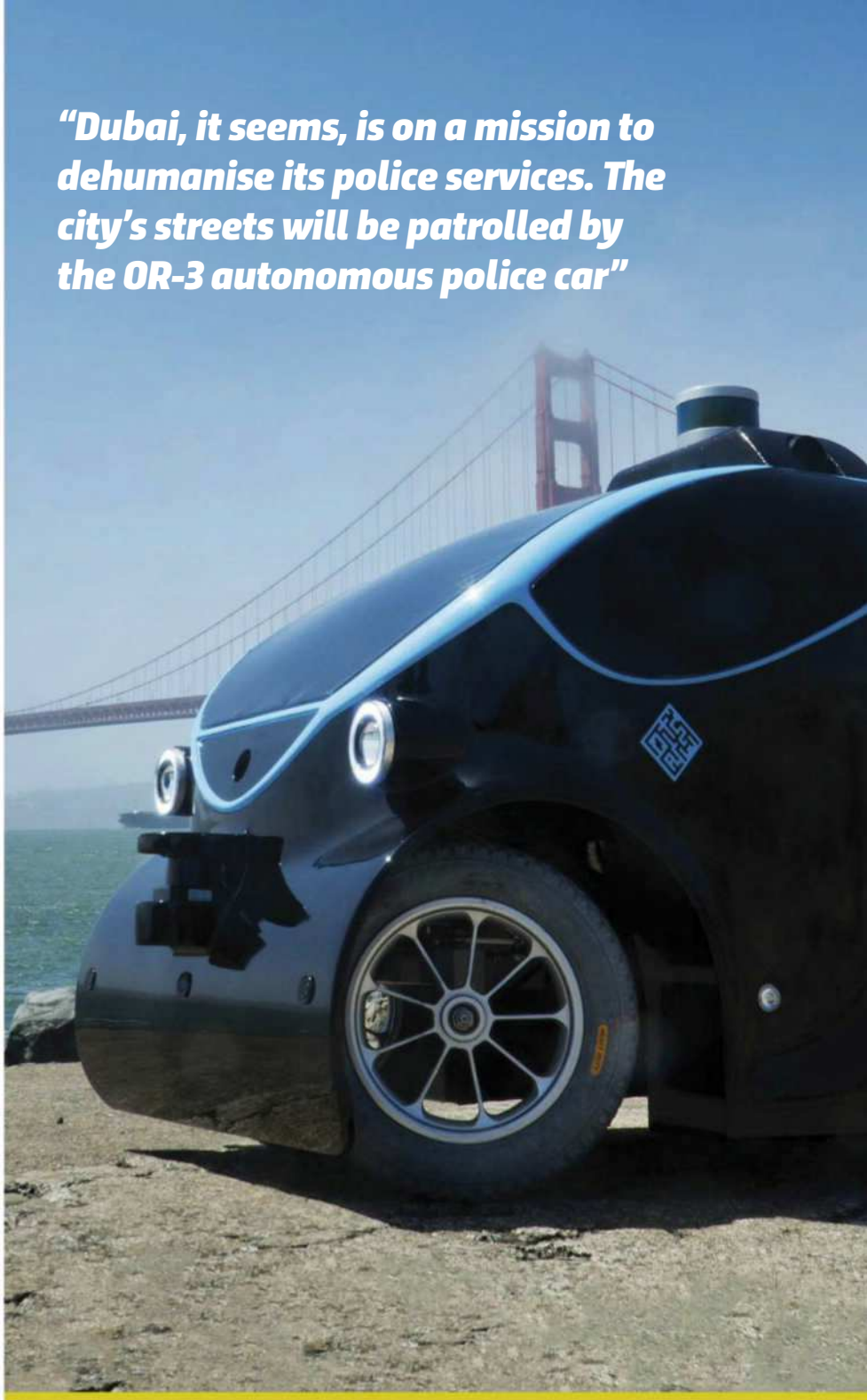


PHOTO: OTSAW, SHUTTERSTOCK

2. SELF-DRIVE SURVEILLANCE

Dubai, it seems, is on a mission to dehumanise its police services. The city's streets will also be patrolled by the OR-3 autonomous police car, the Dubai police force announced last year. At under a metre high, the OR-3 is too small to take a human passenger, but it doesn't need one. The vehicle boasts a range of high-tech navigation and data collection tools: GPS, a laser scanner, thermal imaging and LIDAR – a remote-sensing method used in surveying. It's designed for 360° surveillance and can track down police suspects using its biometric scanners. Oh, yeah, and who needs police helicopters? The OR-3 comes complete with a mini-drone that can be launched for aerial surveillance.

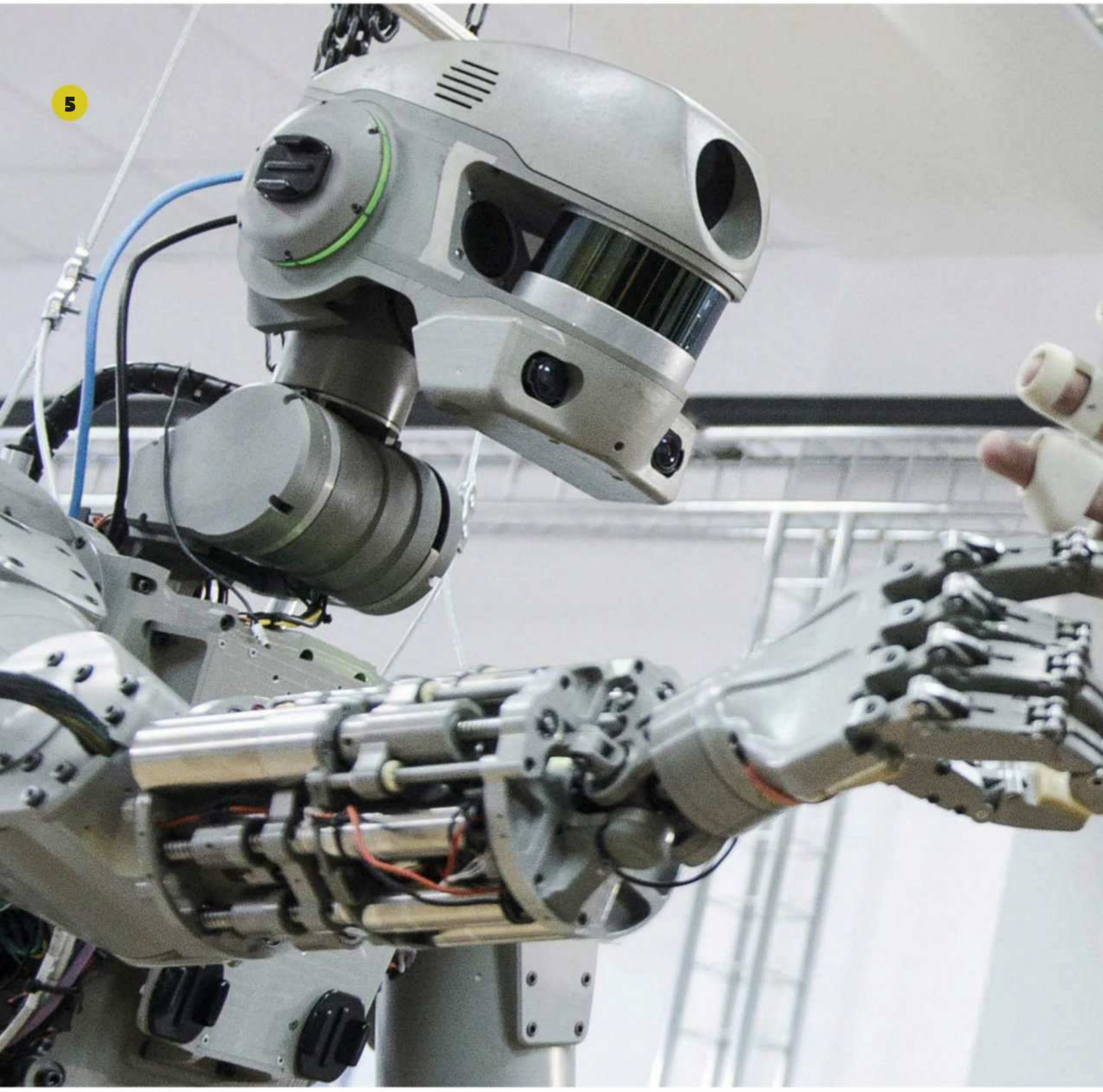
3. SWAT-BOTS

It looks like a tiny tank with a police shield attached, and that's basically what it is. The 'SWAT-Bot' is designed to batter down doors and protect tactical teams of up to 12 people when approaching armed suspects. It can also be operated remotely.

Created by twin brothers, Mike and Geoff Howe of Howe and Howe Technologies, it was developed in conjunction with Massachusetts police, although so far there have been no reports of the SWAT-Bot being used for anything but drills.

4. THE SECRET POLICE

Another tool for tactical teams, the Throwbot XT is a miniature stealth robot that weighs little more than a rugby ball and can be thrown – literally – into any situation where a human counterpart might attract too much attention. Once in situ, it can be directed to quietly survey its surroundings, transmitting video and audio to an operator. Its makers, Minneapolis-based ReconRobotics, claim that the Throwbot can see in complete darkness and can be used to locate hostages and armed suspects.



5. SHARP SHOOTER

Russian robot FEDOR is destined for the stars (okay, near-Earth orbit). The Russian space agency Roscosmos plans for the robot to pilot the unmanned Federatsiya spacecraft on its first mission in 2021. The bot's fine motor skills give it the dexterity to screw in light bulbs and drive cars, but have also led to speculation about other potential roles. That's because in April last year, FEDOR was filmed being trained to shoot two guns at once, firing double-handed like a gunslinger from the Wild West, and both on target.

While Russian officials were quick to point out that they are not "creating a Terminator", some people have jumped to other conclusions. Meanwhile, scientists at Russia's Advanced Research Fund, which built FEDOR in

partnership with Android Technics, are also developing robots to assist special forces in the field. They are working on a prototype for a robot that will "deliver ammunition to the battlefield, support the sniper, and, if necessary, help in evacuation of the wounded," the organisation's deputy head of robotics, Alexei Kononov, told the Russian news agency RIA Novosti last October.

6. BOTS ON THE BEAT

A railway station in Henan province, China, has its own RoboCop in the form of the E-Patrol Robot Sheriff (top image). Equipped with facial recognition software, it's designed to identify and track criminals, and also functions as an environmental monitoring station thanks to its air quality and temperature sensors. These reportedly came in handy on the robot's first day on the job, when it detected a fire.

Meanwhile, California has been trialling robotic security guards in shopping malls and car parks. The US-made Knightscope K5 (bottom image) works like CCTV, transmitting data to a control centre. Undeterred by a collision with a toddler and a self-'drowning' incident in a fountain, Knightscope recently unveiled K5's shiny new successor, K7 – a three-metre-long buggy that can patrol on grass or sand.

PHOTO: GETTY X2, KNIGHTSCOPE

ROBOCOPS: THE NEW FACE OF THE POLICE, OR AN ELABORATE PR STUNT?

Prof Alan Winfield, a robot ethicist at the University of the West of England, discusses the pros and cons of police robots

What do you think today's robots can usefully contribute to the police service?
The one positive thing that I can see is a kind of reassuring presence. That's if they're trusted. It depends on how people react to the robots, but robots moving around a shopping mall, for instance, could prove reassuring – even if not as much as real, live human police. Having said that, I do appreciate there are cultural differences, and in some countries, particularly in the Far East, robots are likely regarded with a greater level of trust than in the UK.

There's talk of robots being given greater powers. Could they make arrests?
The power to arrest someone is a privileged duty because you are essentially making a judgment about whether that person has committed a crime. If a human makes that judgment and it turns out to have been incorrect, then they can be held accountable. But you can't sanction a robot: they can't be held responsible for their own behaviour, at least until the far-distant future.

So robots could never be fully-fledged police officers?
I'm not saying it's impossible that we could build robots that have some responsibility, but for something to be responsible in law, it's got to have some kind of personhood. Giving a robot personhood right now is absurd – it's like giving your washing machine personhood, or your mobile phone. Think of a robot like Data from *Star Trek*, a robot that effectively earns trust and genuine friendship from its human colleagues, that demonstrates its reliability over many years of companionship, and actually cares about the people it works with. That's what we'd need in order to be able to assign it consequential responsibilities like the power to arrest someone. I think we're looking hundreds of years into the future before we can build such a machine.

What kinds of problems could a robot police officer encounter?
There have been examples of robots being hassled by kids, although you can't really abuse a machine, as such. Another problem is the robot being 'gamed'. In other words, people will work out what its weaknesses are, where its senses are, and then try and back it into a corner or persuade it to go in a particular direction.

Another big worry that I have is hacking, and we know from experience that no systems are unhackable. We've seen incidents of driverless cars being hacked, and even devices apparently as benign as webcams. So a malicious person could hack into a police robot and cause all kinds of havoc, particularly if they're remotely controlling the robot. All told, you've got a whole spectrum of potential problems with robot police, and these will all happen – there's no doubt about it.

Who's responsible if someone is injured by a police robot, or if it makes a mistake?
The owner of the robot probably ultimately has responsibility, but if there was a manufacturing fault, it's no different to your car. If you crash into someone and cause injury, it's your responsibility, but if it turned out the crash was partly caused by a significant fault in the car, then the responsibility might be shared with the people who maintained your car – who fixed the brakes the last time, for example – or even with the car's manufacturers, who,

PHOTO: ALAMY, SHUTTERSTOCK

"A malicious person could hack into a police robot and cause all kinds of havoc, particularly if they're remotely controlling it"

for whatever reason, might have built in some design flaws.

Do we need any new laws to deal with potential police robot incidents?
Robots are no different from any other manufactured object. They're human-made artefacts, and we have tonnes of legal history of accidents with machines, in which culpability is discoverable and people are held to account and end up paying for it, often through their insurance, of course. So I think it's quite wrong to give robots any special status in this regard. I suspect the new law that's needed is more around issues of transparency. So you've heard of a black box in an aeroplane – it's a flight data recorder, and when air accidents happen, the first thing that the investigators do is look for the recorders. They're absolutely crucial to finding out what went wrong in the accident. I think that robots, especially those in roles such as the police, absolutely must be fitted with a robot equivalent of the flight data recorder that basically records everything that happens to it. In fact, I recently wrote a paper on this: *The Case For An Ethical Black Box*. I think it should be illegal to operate driverless cars, care robots or police robots without one.

There must be some advantages to robot police officers. Couldn't they be completely fair and impartial in a way that a human cannot?
The experience of AI [artificial intelligence] has shown that this is not the case. It's very difficult to build unbiased AI systems. Face recognition algorithms are typically quite good at recognising white faces, but not other ethnicities, and this is simply a bias that reflects the fact that the datasets used to train the facial recognition algorithms have not been properly designed. So the idea that a robot would be more impartial is... I mean, it depends on the kinds of decisions it's making. Unfortunately, there are examples of bias in AI systems being reported all the time.

So are police robots more of a publicity stunt than a realistic application for humanoid robots right now?
Yes, I think the worry is that it can be a PR stunt, particularly if you're a country that is very serious about investing heavily in robotics and AI. I think it helps to raise the visibility and the profile of that level of investment so, yes, there's probably a big publicity aspect to it.

Hayley Bennett is a science writer based in Bristol.

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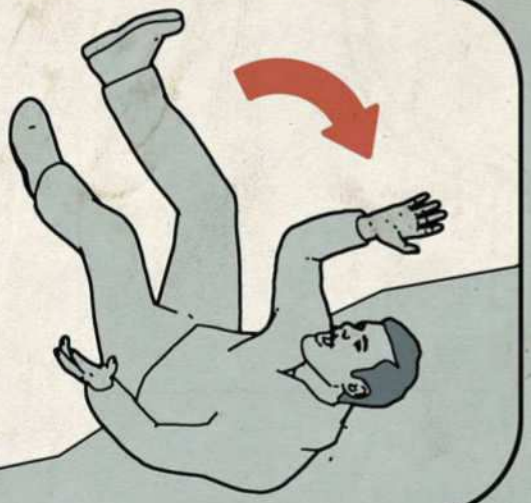

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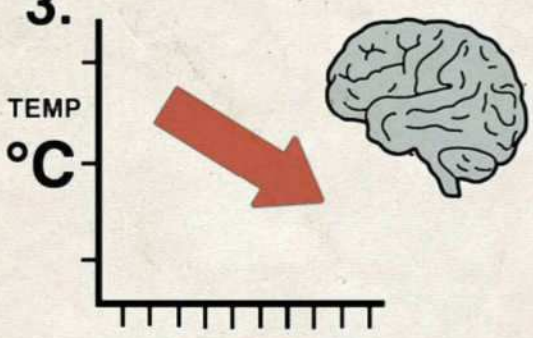

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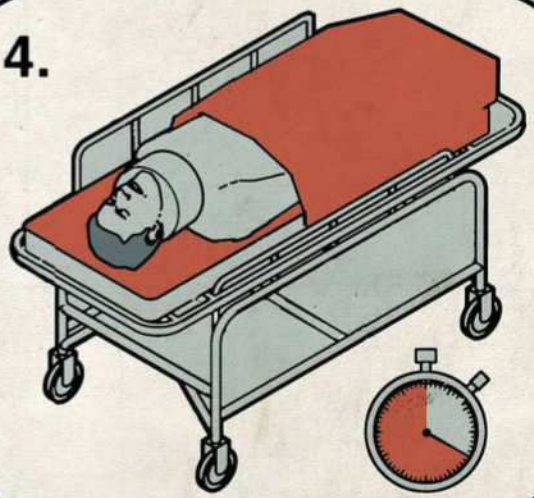

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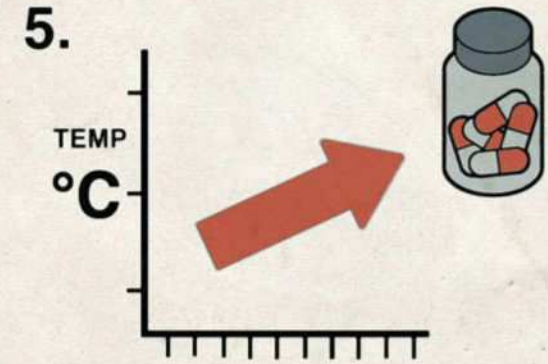


6.

IN COLD BLOOD

We all know that hypothermia can kill – but increasingly, it's also being used to save lives

WORDS: **TOM IRELAND**

Early on the morning of 30 December 2007, a drunk 41-year-old man left a party in the city of Stokmarknes, in northern Norway. Soon after, he slipped and fell into a steep-sided ditch. Plunged neck-deep in the freezing water, he was unable to get out and spent nearly an hour in the ditch before passers-by spotted him and hauled him out.

Despite their best efforts to warm him up, the man remained severely chilled, largely thanks to the air temperature being a biting -2°C. Shortly after the paramedics arrived, he fell unconscious, stopped breathing and went into cardiac arrest. It would be seven hours before his heart started beating properly again, and for five of those he was technically dead. Somehow the extreme cold – the very thing that had caused the man's heart attack in the first place – had saved his life.

In healthy humans, the body maintains a core temperature of between 36.5 and 37.5°C – anything below this is a dangerous condition known as hypothermia. When someone's body enters a hypothermic state, their metabolism slows down, their heart rate slows, organs start to shut down and eventually, their heart stops beating. Within a few minutes of the heart stopping, the body's oxygen reserves are depleted and cells start to ▶

PHOTO: GETTY

ABOVE: **A molecule of human haemoglobin, the protein that carries oxygen in the blood**

produce toxic chemicals. This quickly starts to cause irreversible damage to the delicate tissues of the brain. Even if resuscitation is successful, the danger is not over: most cardiac arrest patients whose hearts are restarted end up dying in hospital from the damage caused by the return of oxygenated blood throughout the body; up to 30 per cent suffer permanent brain damage.

However, there's an old saying in the medical profession: "No one's dead until they're warm and dead". In cases of cardiac arrest caused by extreme cold, an extraordinary thing can happen: the reduction in body temperature reduces the brain's need for oxygen. If cooling is rapid enough, it can help prevent toxic chemicals accumulating while the heart has stopped, and continues to protect the brain when oxygenated blood returns.

The Norwegian man arrived at a nearby hospital at 5am, with a temperature of just 25.5°C – easily in the most severe category of hypothermia. After attempts to warm him failed, medics called for a helicopter from the University Hospital of North Norway (UNN), a better-equipped medical centre over 250km away. Doctors continued to do CPR on the man, but by the time the helicopter reached UNN with the patient onboard it was nearly 9am. He had been technically dead for nearly five hours.

At 11.37am, after hours of work by teams of UNN staff, the man plucked from the icy ditch was finally revived, and weaned off machines that had been artificially pumping blood around his body. It had been nearly seven hours since he had entered cardiac arrest – one of the longest resuscitation periods ever recorded. Miraculously, he went on to make a full recovery, with no signs of brain damage at all.

"His metabolism had decreased by 60 to 70 per cent," says Lars Bjertnaes, a professor of critical care at The Arctic University of Norway, who examined the case in detail. "His oxygen needs probably could be met by a cardiac output of about a quarter of normal."

BACK TO THE COLD SCHOOL

Stories like this have inspired a range of medical treatments that deliberately induce cold states in patients. It's seen as a cutting-edge treatment, but reports of doctors using extreme cold to keep people alive actually go back centuries. A paper on 'the Russian method of resuscitation' from 1803 describes

"There's an old saying in the medical profession: no one's dead until they're warm and dead"

ABOVE LEFT: **Dr Sam Parnia, of New York's Stony Brook University Hospital, believes therapeutic hypothermia has the potential to change our understanding of death**

ABOVE RIGHT: **The darker areas in this CCT (coloured computer tomography) image of a cardiac arrest patient's brain show where damage has been caused by a lack of oxygen**

covering cardiac arrest patients with snow to boost their chance of survival. Meanwhile, in 400 BC, Greek physician Hippocrates advocated packing wounded soldiers in ice and snow when moving them.

Since the 1990s, putting patients into a state of hypothermia has been standard practice in open heart surgery, and in the treatment of babies born with heart defects. Here, doctors must 'turn off' the circulatory system in order to operate on the heart; reducing body temperature allows them to do this for long periods without causing tissue damage.

Over the past decade, the use of 'therapeutic hypothermia' – also known as targeted temperature management (TTM) – has become widespread in the treatment of heart attacks and strokes. The concept is the same: use low temperatures to protect against the damaging cellular reactions that occur when the oxygen supply is cut off, and perhaps more importantly, prevent damage when blood and oxygen return after treatment.

"We try to reach hypothermia as soon as possible," says Gladys Janssens, a cardiology researcher at VU University Amsterdam who has studied different methods of cooling heart attack patients. "After reaching hypothermia, we try to keep the temperature as close to the goal temperature as possible for 12 to 24 hours. Lower temperatures can be a risk for bleeding complications and heart rhythms, and higher temperatures might negate the protective effect."

While the idea of cooling critically ill patients is now widely accepted, the optimal temperature to keep them at, and the method of getting them cold, is still being debated. Older methods cooled heart attack patients to 33°C, but more recent studies have shown cooling by just one degree to 36°C could be equally as effective, with fewer risks. There are also a number of different methods to get patients cold – the most simple being water-cooled blankets or adhesive pads placed on the body, with more advanced techniques involving the insertion of catheters into the body and balloons circulating ice-cold saline. Both have their pros and cons.

"The blankets are cheap, quick and less labour-intensive. But fast application does not automatically mean patients reach hypothermia more rapidly," says Janssens. "The disadvantage of the catheters is that a trained physician has to insert them."

Throughout treatment, drugs must also be administered to stop patients' natural shivering response. Common complications of being kept cold for so long include severe fever, infections and damage to the skin. After the danger period is over, patients must be warmed slowly – no faster ▶

PHOTOS: SCIENCE PHOTO LIBRARY X2, MARTIN ADOLFSSON

HOW THERAPEUTIC HYPOTHERMIA WORKS

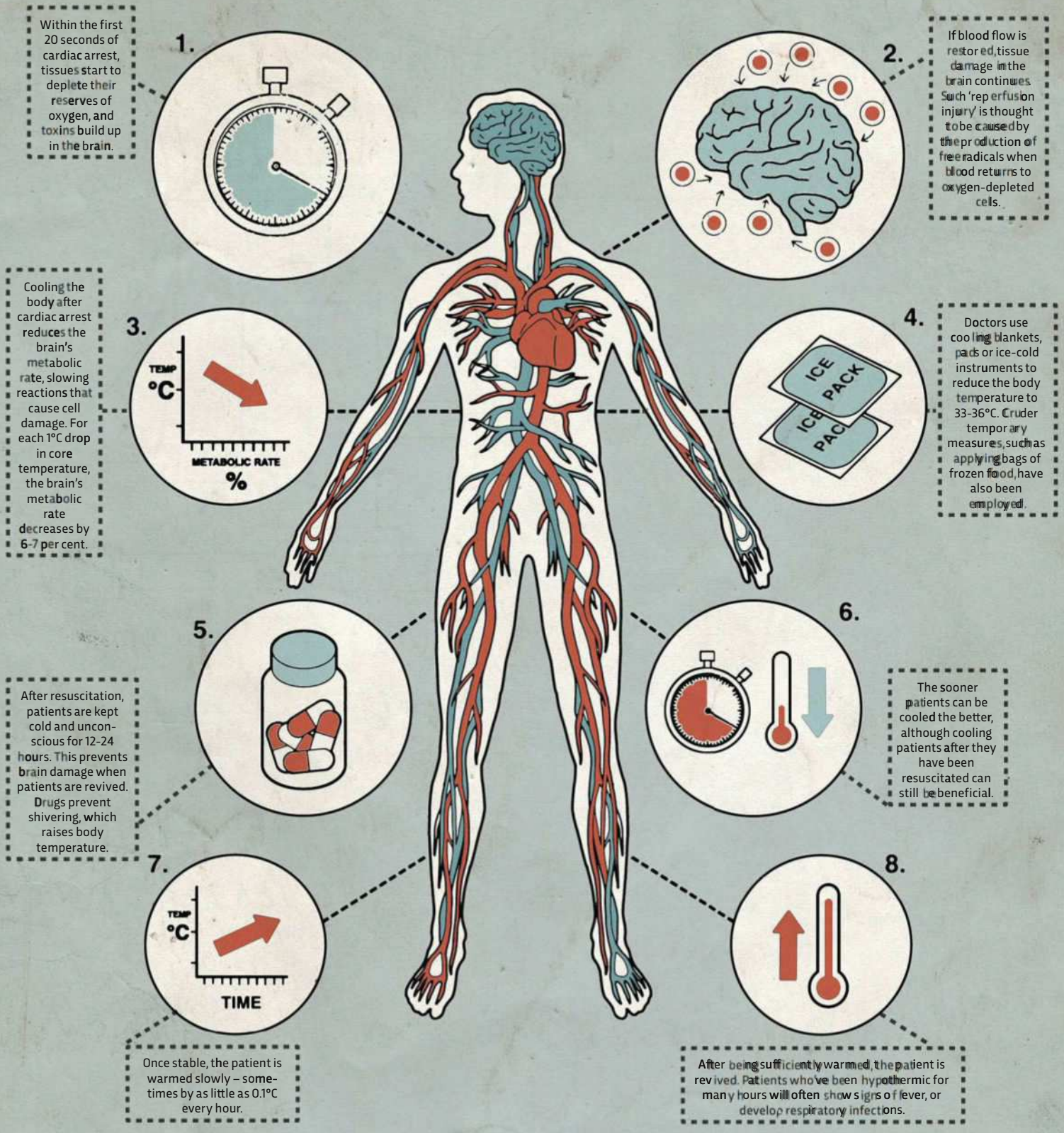


PHOTO: SCIENCE PHOTO LIBRARY ILLUSTRATION: SON OF ALAN

than 0.5°C per hour. It's an ordeal for the body to go through, but TTM is the only post-resuscitation technique that can significantly decrease the chance of brain damage after a cardiac arrest.

FIRE AND ICE

With cooling equipment increasingly common in medical centres, doctors are now exploring what other conditions induced hypothermia may help to treat. Dr Sam Tisherman, a surgeon and professor of critical care medicine in Baltimore, has started trials to drastically cool patients who arrive in his emergency department bleeding to death – often from multiple gunshot wounds.

"Trauma patients normally enter cardiac arrest because they have lost so much blood there just isn't enough for the heart to work," says Tisherman. "The problem is we just can't sew them up fast enough – for severe blood loss their chances of survival are around 5 to 7 per cent."

Tisherman's experimental technique involves pumping ice-cold saline directly into the body to replace lost blood, inducing a very deep state of hypothermia – as low as 15°C – not unlike the state known in science fiction as 'suspended animation'. This is not cooling by a few degrees after a controlled cardiac resuscitation; it's more like freezing someone and operating on them while they're technically dead.

"The issue for us is time," says Tisherman. "This is very different from teams who have resuscitated someone having a cardiac arrest and are trying to protect the brain from damage. We have someone with no pulse, who's losing so much blood CPR is not effective. We're just trying to buy time."

Somebody with no blood reaching the brain might normally expect to die or suffer irreversible brain damage within five minutes. Tisherman says his technique has enabled people to survive after up to an hour of surgery before being slowly warmed and revived. "In the lab, we've even seen as much as two or three hours," he says.

Tisherman believes it may be possible to use cooling to treat a range of other conditions, even at the scene of an emergency. "There are now teams that will try to start the cooling outside the hospital," he says. "There's an image being shared online of paramedics in Germany attending to a man suffering cardiac arrest in a grocery store. They piled bags of frozen French fries on him to cool him down."

A range of studies are now investigating cooling as a way to protect against damage caused by conditions as varied as head injuries, meningitis, spinal cord injuries and liver failure. In the US, a woman arriving at hospital clinically brain-dead after committing suicide with a cocktail of sedatives and antifreeze was successfully 'managed' with therapeutic hypothermia for 36 hours while doctors worked on her. She awoke within 48 hours of being warmed up and made a full recovery.

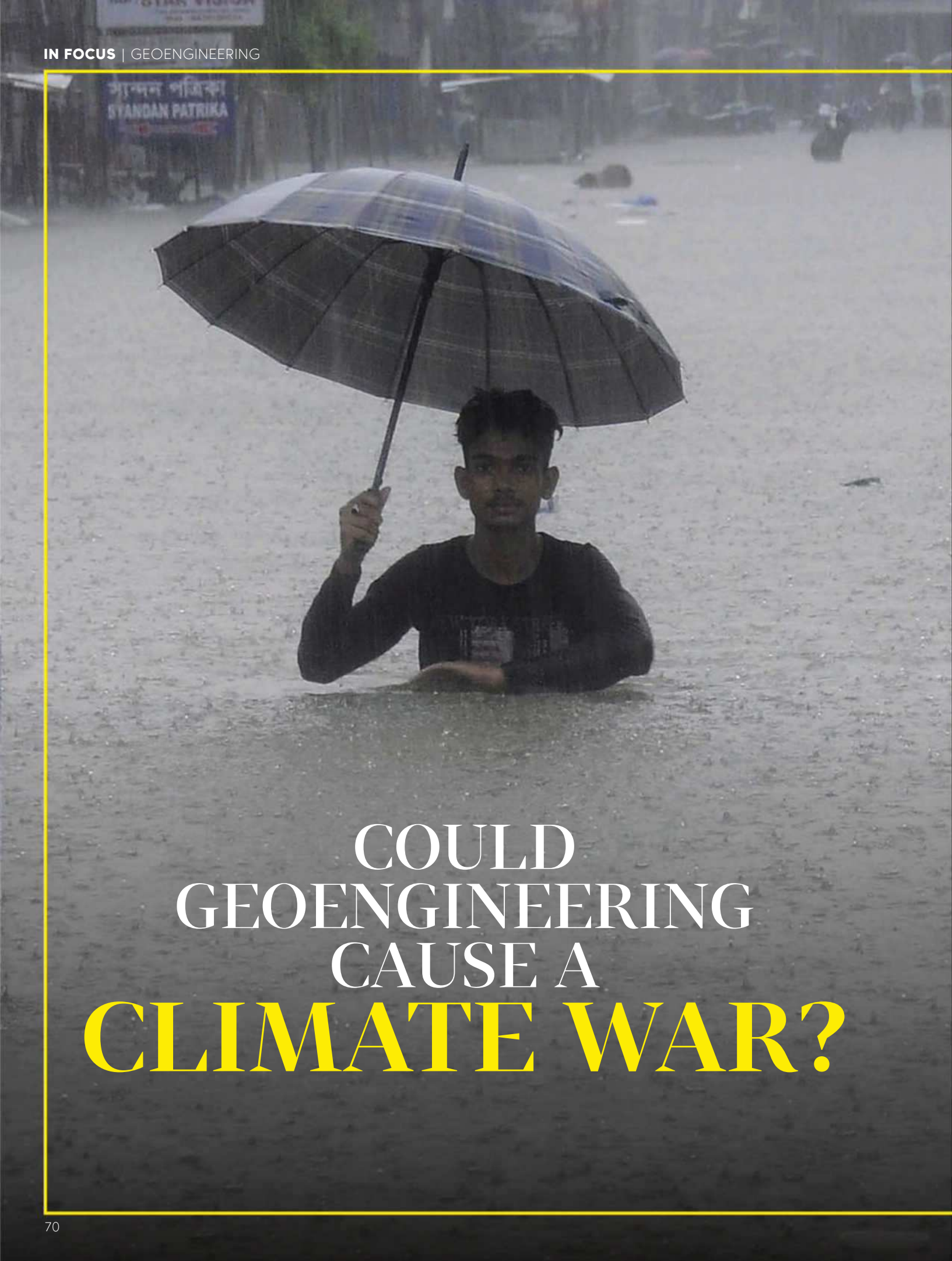
The power of cold to stave off death might even mean we need to re-evaluate our definition of death. Researchers such as Dr Sam Parnia, a professor of critical care medicine, have suggested that techniques like therapeutic hypothermia are making it difficult to tell what 'dead' really means. In his book *Erasing Death*, Parnia argues that currently, the point at which medical staff stop trying to revive patients and declare them dead is entirely arbitrary.

In the near future, Tisherman hopes that the miraculous effects of cold temperatures could be replicated by a more practical medical equivalent. "We don't use the term 'hypothermia', because the hope is that we could eventually find a drug that stops the brain and body needing oxygen like cold does," he says. "That would be a lot easier."

ABOVE:
Chilling the body to temperatures as low as 12°C is now common practice during open heart surgery

"We have someone with no pulse, who's losing so much blood CPR is not effective. We're just trying to buy time"

Tom Ireland is a freelance science journalist, and editor of *The Biologist*, the bi monthly magazine of the Royal Society of Biology. He can be found on Twitter at @Tom J_Ireland



COULD GEOENGINEERING CAUSE A CLIMATE WAR?

IF COUNTRY LEADERS MANIPULATE THE WEATHER TO DO THEIR BIDDING, COULD THEY CREATE POLITICAL TENSIONS, OR EVEN ALL-OUT WAR?

PHOTOS: GETTY, SHUTTERSTOCK

WORDS: CLIVE HAMILTON

Clive is professor of public ethics at Charles Sturt University in Canberra, and the author of *Earthmasters: The Dawn Of The Age Of Climate Engineering* (£16.99, Yale University Press).

"COULD WE BE LOOKING AT THE DAWN OF A NEW KIND OF WAR – ONE FUELLED BY A BATTLE FOR DOMINANCE OVER OUR CLIMATE?"

Climate change is a problem in desperate need of a solution. According to the authoritative Carbon Action Tracker, even if all nations honour their pledges to cut their greenhouse gas emissions, the globe will still warm by around 3.2°C by 2100 – with catastrophic consequences for humanity and the animal kingdom.

If cutting greenhouse gas emissions isn't enough, is it time for a plan B? Recent times have seen a surge of interest in geoengineering: China has recently embarked on a substantial research plan, while in the US, Prof David Keith of Harvard University is planning to launch a high-altitude balloon this year to test the feasibility of spraying reflective particles into the stratosphere. Meanwhile, other researchers are looking at the possibility of increasing the brightness of marine clouds to reflect more sunlight back into space.

But there are a number of risks, and not just because we're unsure about how effective these interventions would be. There are fears that one country's efforts to solve its climate problem could inadvertently mess up the weather elsewhere, creating a new source of political tension. And ultimately, this leads to a worrying question: could we be looking at the dawn of a new kind of war – one fuelled by a battle for dominance over our planet's climate system?

THE PROBLEM WITH GEOENGINEERING

Geoengineering is defined as a deliberate, large-scale intervention in the climate system, and schemes come in two varieties. The first type aims to remove carbon dioxide from the atmosphere. This can be done by capturing it from the air using natural or artificial means; making biochar (a type of charcoal) from vegetation waste; or adding lime to the oceans to reduce their acidity and therefore maintain their ability to absorb carbon dioxide from the atmosphere. The greatest hurdle for these

ABOVE: **Large volcanic eruptions can cool the planet by preventing a little solar radiation from reaching us. Some geoengineering schemes work in a similar way**

ABOVE: **Agriculture in South and East Asia is reliant on monsoons, but there are concerns that geoengineering could disrupt annual rainfall**

LEFT: **Biochar can lock carbon in the soil, and could be used to reduce carbon dioxide in the atmosphere**

PHOTOS: GETTY X2, ALAMY

schemes lies in finding somewhere to permanently store the huge quantities of carbon. The deep ocean offers one possible solution, but we're still a long way from a feasible method of doing this.

The second kind of geoengineering scheme is known as solar radiation management or albedo modification. These techniques look to reflect a small amount of sunlight away from the planet to reduce warming. Some of these proposals are relatively benign, but also pretty ineffective. The technology receiving most attention – and the one most likely to be deployed because it's cheap and feasible – is known as sulphate aerosol spraying.

The idea is to spray sulphur dioxide or sulphuric acid into the stratosphere or upper atmosphere to form tiny particles that reflect an extra 1 to 3 per cent of incoming solar radiation back into space, thereby cooling the planet in the way that large volcanic eruptions are known to do.

In effect, humans would be installing a radiative shield between the Earth and the Sun: one that could be adjusted by those who control it to regulate the temperature of the planet. The models indicate that if we reduced the amount of sunlight reaching the planet, the Earth would cool fairly quickly, although with less effect at the poles, which are warming more rapidly.

A 2010 study published in *Nature Geoscience* found that, under a solar geoengineering regime, there would be different responses across large regions, making consensus about how much to reduce incoming solar radiation difficult, if not impossible.

Some atmospheric scientists, like Dr Alan Robock at Rutgers University, argue that the complexity of the climate system means that it's difficult to draw firm conclusions about the consequences of such a radical intervention. They point out that the chemistry of the upper atmosphere – including the ozone layer – is complicated and poorly understood. Reducing the amount of sunlight reaching the Earth in a computer model may give little clue as to what would happen in the actual climate system if a layer of sulphate aerosols were injected into it.

One worry is that, combined with increased water vapour as a result of global warming, adding sulphates to the upper atmosphere could be a lethal cocktail for ozone loss, speeding up chemical reactions that destroy this crucial gas. Other studies indicate that, depending on the kind of aerosol spraying programme, the South Asian and East Asian monsoons could be disrupted. Tropical rainfall depends on differences between temperatures on ➤

land and sea, and some models show that by changing the temperature ratio between land and sea, solar geoengineering could suppress monsoon rains, affecting food supplies for millions of people.

However, global warming itself is changing precipitation patterns around the world (broadly speaking, dry regions are becoming drier and wet ones wetter) so a solar shield may improve rainfall in some regions that are drying out. It's here we get to some of the most difficult issues associated with geoengineering.

UNKNOWN UNKNOWNS

If the most sophisticated models cannot provide a firm answer regarding how solar geoengineering would affect the actual global climate, nor can experiments. Only full-scale implementation would provide a clear idea of its impacts.

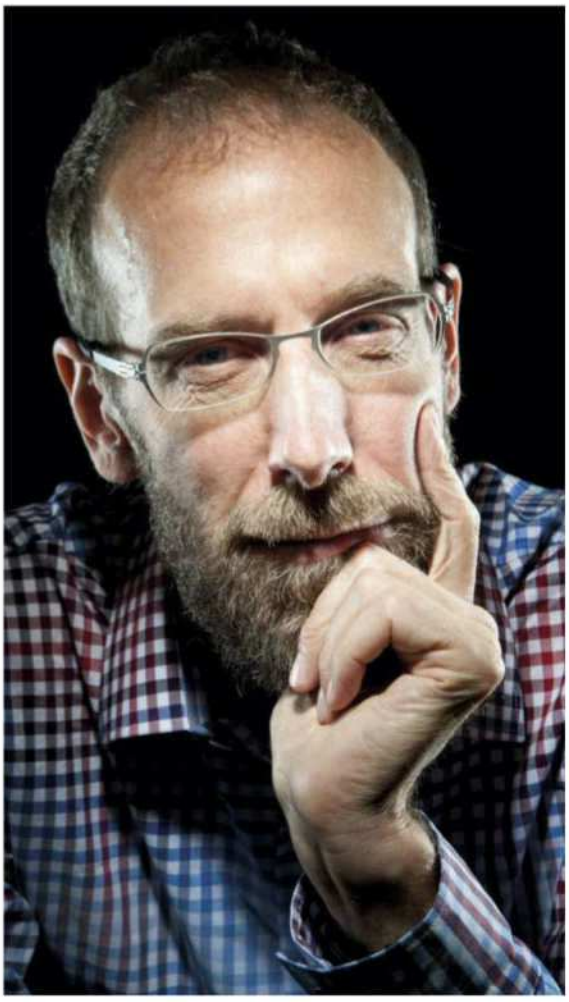
Even then, we'd need at least 10 years of global climate data before we had enough information to separate out the effects of sulphate aerosol spraying from natural climate variability and, indeed, from the effects of human-induced climate change. To compound the risks, if after 10 years we had accumulated enough data to decide that our intervention was not a good idea, it may be impossible to terminate the solar shield. Why should this be so?

For some time, ecologists have known that the *rate* at which the globe warms is a greater threat to ecosystems than the *amount* of warming, because a slower rate of warming gives plants and animals more time to adapt. If the solar shield causes some nasty unintended effects (including conflict between nations), removing it suddenly would cause the suppressed warming 'rebound'. It's been estimated that if warming occurs at a rate of 0.3°C per decade (well within the estimated rebound range) then only 30 per cent of ecosystems could adapt and survive.

So we may find that, once deployed, removing the shield becomes too risky; we'd be stuck with it. The danger would be multiplied if we failed

PHOTOS: WEBB CHAPPELL, FLPA

"SOME EXPERTS BELIEVE THAT CLIMATE CHANGE-INDUCED DROUGHT, HIGH FOOD PRICES AND MIGRATION TO CITIES NUDGED SYRIA INTO CIVIL WAR"



LEFT: **Cloud-seeding substances, which provide nuclei around which clouds can precipitate, being blasted from a plane**

ABOVE RIGHT: **This year, Prof David Keith from Harvard University hopes to launch a balloon to spray reflective particles into the stratosphere**

to take the opportunity to cut greenhouse gas emissions sharply while the shield was in place. This is perhaps the greatest hazard of going down this path.

POLITICS, POLITICS

Some technologies are inherently political in the sense that they increase the power of those who control it and reduce the power of those excluded from it. Imagine if the US government decided to install a solar shield that allowed it to regulate the climate. The government would wield great power over all those US industries that depend on the weather, while also being able to influence the climate in other parts of the world, creating immediate strategic tension.

Paradoxically, solar geoengineering can also be seen as a means of preserving social and political structures that are threatened by measures to cut carbon emissions. Instead of taxing fossil fuels, banning coal mining and restricting air transport, those profiting from these activities might welcome a technofix like sulphate aerosol spraying.

Indeed, in the US, conservative think tanks that have been at the forefront of climate science denial have shown an interest in solar geoengineering. It's cheap and protects any vested interests. Geoengineering promises to turn a drastic failure of the free enterprise system into a triumph of human ingenuity. And they are more inclined to agree with Prof David Keith that an artificial Earth shaped by humans is not intrinsically inferior to a natural one.

At a deeper level, the implicitly autocratic nature of global climate regulation has an appeal to those on the political right just as it frightens those on the democratic left. It's hard to imagine a government in charge of a solar geoengineering project holding a referendum on whether the Earth's temperature should be reduced by one degree or two.

The control of the Earth's weather could become the responsibility of a kind of 'Climate Regulation Agency', staffed by a technocratic elite whose task would be to continuously collect a vast array of weather information, feed it into data systems, separate out the effects of the solar shield from other factors, and advise the relevant department as to how many planes loaded with sulphur dioxide should be sent up next week and where they should dump their loads.

CLIMATE WARS

Military planners recognise climate change as a 'threat multiplier'. US defence chiefs, among others, have incorporated a changing climate into their military planning and equipment supply. Climate change is expected to create political instability; indeed, some experts believe that climate change-induced drought, high food prices and migration to cities nudged Syria into civil war.

If that's true – and we can only guess at how much conflict there might be in a world 3°C warmer – mitigating warming by geoengineering ought to create a more peaceful world. But it's not so straightforward.

When hit by a devastating flood, drought or storm, a community will tend to see it as an act of God – a natural event that it just has to cope with. But what if we believed that the death and destruction were caused not by nature but by someone manipulating the weather? If another nation were engineering the climate, its politicians' denials would fall on deaf ears, and not just because humans naturally look for someone to blame. If a nation had embarked on a system-altering form of climate engineering like sulphur dioxide spraying, it would be virtually impossible to work out whether an extreme weather event somewhere in the world was due to natural variability, human-induced climate change or climate manipulation. And climate manipulation would quite likely get the blame.

The government of China, faced with a catastrophic drought in the north of the country, might decide its survival demanded rapid global cooling. But sending up planes to spray sulphur dioxide might deprive India and Pakistan of their monsoon rains, bringing on famine. Three nuclear-armed nations would then be in conflict over weather patterns that affect the survival of millions of their citizens.

It's hard to know who might first be tempted to regulate the global climate. Given the severe environmental and geopolitical risks, and the deep ethical divide over whether humans should 'play God', governments in democratic countries may be hamstrung. Authoritarian leaders who do not need public approval to act may have a freer hand. Do we want Vladimir Putin or Xi Jinping controlling our weather?

A dictator with his hand on the global thermostat is a scary prospect. But imagine if several poorer nations (let's say Bangladesh, Tuvalu, the Maldives and Ethiopia) clubbed together and declared:

"The rich countries that caused global warming promised to cut their emissions, but they have not done so. Our people are dying, so we must take unilateral action. We are sending up a fleet of planes to spray sulphur dioxide."

Now the moral calculus leaves us uncertain what to think. Don't they have the right to save themselves from an existential threat, even if by risky means? What would it mean for floods and storms in other countries? Would the United States or China be entitled to shoot down their planes?

Reaching a consensus to regulate the Earth's climate would, in the words of a 2013 study, "pose immense challenges to liberal democratic politics". But then, liberal democratic politics does not have a great record responding to climate change, either. The elected president of the US, Donald Trump, has announced that his country will be pulling out of the Paris Agreement, an action that will slow emissions reductions and expose millions of people, especially poorer individuals, to the devastating effects of a warming world.

In the circumstances, the only acceptable answer is a global agreement to regulate research into geoengineering. If it ever comes to deployment, conflict could be avoided only if an inclusive international institution makes the decision. Without it, one nation would control the climate of others, and those others will be tempted to engage in their own 'counter-geoengineering'. And then we really are in trouble.

ABOVE: **Emissions from the steel industry contribute towards air pollution. Average global temperatures have risen by more than 1°C since before the Industrial Revolution**

AN ALTERNATIVE VIEW

Peter Irvine *is a climate scientist at Harvard University who researches solar geoengineering. He argues that the benefits of the technology could outweigh the risks*

I've been working since 2009 to understand the potential and limits of geoengineering, and Clive Hamilton paints a picture of this technology that I simply do not recognise. To address climate change, carbon dioxide emissions will have to be driven to zero, but however fast emissions are cut, the climate will still warm considerably over the 21st Century. It's here that stratospheric aerosol geoengineering could prove an extremely useful tool.

Higher temperatures mean more intense heatwaves; they mean air carries more moisture, causing more intense floods; and they mean more melting of the glaciers, driving up sea levels. Reducing temperatures will reduce these risks, and our work has shown that it doesn't make much difference whether this is done by lowering emissions or by cooling from solar geoengineering. This doesn't mean geoengineering should be a replacement for emissions cuts – indeed, it may introduce some new risks of its own – but it would help to offset some of climate change's worst impacts.

Clive points to the potential dangers of geoengineering reducing monsoon rainfall, but his picture is incomplete. Water availability depends not only on how much rain falls but also on how quickly it evaporates in the heat of the day. The same climate models that show that geoengineering would reduce rainfall also show that it would reduce evaporation, potentially leading to more, not less, water availability for people, crops and ecosystems.

Clive also claims that, because climate control would require detailed technical knowledge to manage, it would somehow lead to the technocrats taking over. Yet our lives depend on the technocrats who manage our electricity grids, our water supply, our transport systems and our internet, and still our societies remain robustly democratic.

"THE COSTS OF GEOENGINEERING ARE LOW, ITS EFFECTS WILL BE FELT QUICKLY AND GLOBALLY"

Clive portrays geoengineering as an idea born of Cold War hubris and pushed by right-wing climate deniers. Instead, I see a well-intentioned proposal that is being critically evaluated by hundreds of researchers around the world, from disciplines as diverse as engineering, economics and international law. Rather than coming from shadowy right-wing think tanks of fossil-fuel interests, funding for geoengineering research comes mostly from governments (which reflects a societal demand for this knowledge) and environmentally minded philanthropists.

Outside of academia, there are also exciting developments. The Solar Radiation Management Governance Initiative is an international NGO that's working to empower scientists and policy makers in developing countries to engage with geoengineering, while in New York, the Carnegie Climate Geoengineering Governance Initiative (led by Janos Pasztor, the former climate science adviser to Ban Ki-moon) aims to bring this topic to the attention of international policy makers at the UN and beyond.

The ratification of the Paris Agreement and the stunning developments in solar and wind power in recent years show that the world has the will and is developing the tools to tackle climate change. Even so, international cooperation in this area remains a notoriously difficult process: the benefits of cutting emissions are global and will be felt in the long run, whereas the costs are felt here and now. So even though all countries agree that they want to limit the impacts of climate change, each country benefits the most by doing the least.

For geoengineering, the picture is completely different. The costs of geoengineering are low, its effects will be felt quickly, and they'll be global in scope. This means that governments will have a real incentive to work together to realise the potential benefits of geoengineering.

So the reality of this technology is rather different from the worst-case scenario pictured by Clive Hamilton. We now need a concerted international and interdisciplinary research effort into geoengineering, and we shouldn't let pessimistic fears get in the way of exploring an idea that might really help in the fight against climate change.

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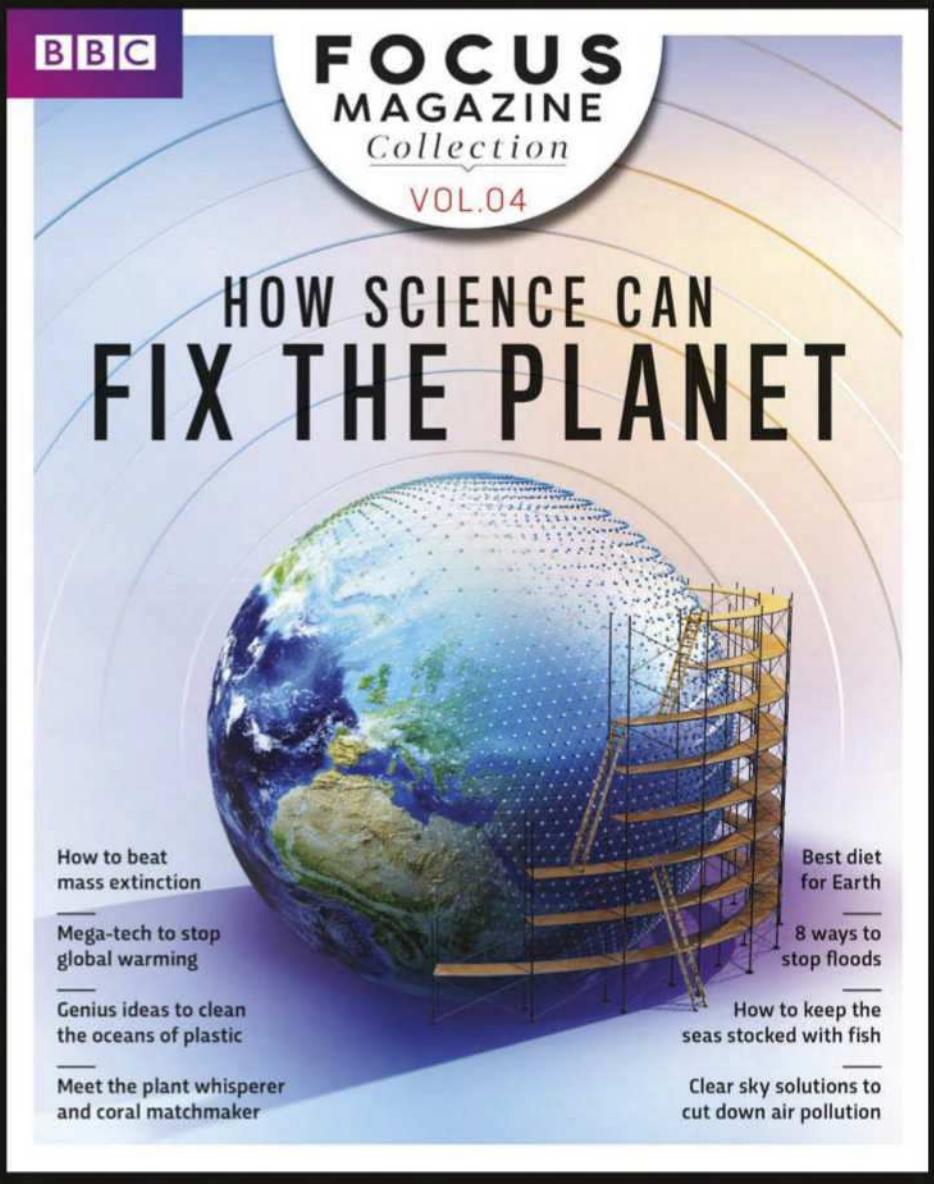

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HELEN CZERSKI ON... CRACKING KNUCKLES

"THE CRACK COMES FROM THE SUDDEN CREATION OF THE CAVITY, AND IT'S LOUD BECAUSE IT'S A VIOLENT PROCESS"

Along with petting puppies and having just one more chocolate, I've added another thing to my list of temptations that humans can't resist: knuckle-cracking. I mentioned this odd habit in a talk that I used to give quite regularly, and almost as soon as the words were out of my mouth, the popping from the audience began.

In the most extreme cases, usually large auditoriums full of teenagers, it would grow like an avalanche: a few lone snaps at the back of the room rolling forwards in an impressive crescendo as everyone else joined in. But finger joints are tiny, and the process of cracking (pulling on a finger joint until it pops) is relatively gentle. What's making this distinctive sound and why is it so loud?

The first step is a bit of anatomy. A joint is where two bones meet. The ends of your fingers' bones are covered with a layer of cartilage, but between the two cartilage layers is a cavity filled with gloopy stuff called synovial fluid, which lubricates the joint as the bones move. Having that fluid-filled cavity there means that the joint can lengthen a little bit – there's no rigid structure holding the whole thing together. The would-be knuckle-cracker pulls on one of the bones, applying a force that could stretch the joint. The interesting thing is that nothing happens immediately. To pull the bones further apart, you need something that's going to fill the new space you create. And then… pop! There it is: a bubble.

This does sound a bit like magic, but the gas was there all along, dissolved in the synovial fluid. Liquids don't stretch much, so when you put a liquid under tension, the only way for it to expand significantly is for it to pull apart and create a hole. Then gas that was dissolved in the liquid will escape because the pressure has dropped (a bit like gas coming out of solution in a fizzy drink when you take the lid off). The crack comes from the sudden creation of the cavity, and it's loud because it's a violent process.

The bubble will sit there until the gas redissolves, which is why the musical contribution of my audiences was short-lived. Once you've already got a bubble, gas can move from the liquid to the bubble quite easily, and if you pull on the joint, the bubble will just expand slowly to fill the gap. It takes about 20 minutes for the bubble to dissolve, and you won't get another crack until you're able to form another bubble from scratch.

But the reason I mentioned knuckle-cracking in my talk at all was to get to the tale of Donald Unger, who won an Ig Nobel Prize in 2009 for his long-term and very personal investigation of the topic. Having been told as a child that this 'bad habit' of cracking his knuckles would lead to arthritis, he cracked the knuckles on his left hand (but not his right) twice a day for 50 years – just to see what happened. At the end of that time, he didn't have arthritis in either hand, and subsequent medical science has backed up the idea that it won't do you any harm.

Dr Helen Czerski is a physicist and BBC presenter. Her latest book is *Storm In A Teacup* (£18.99, Transworld).

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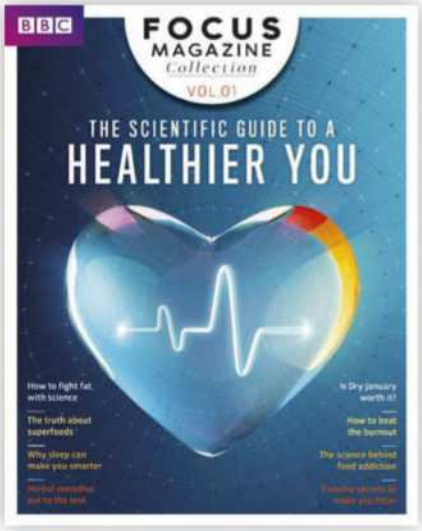

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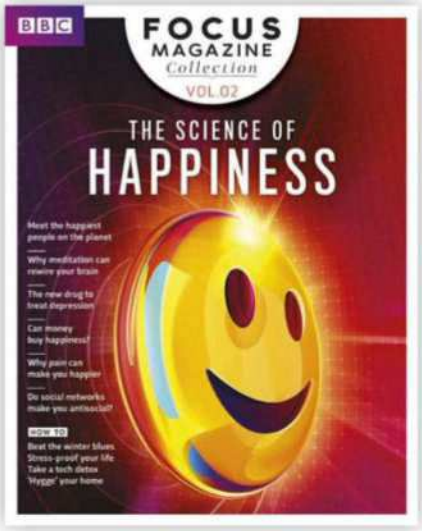

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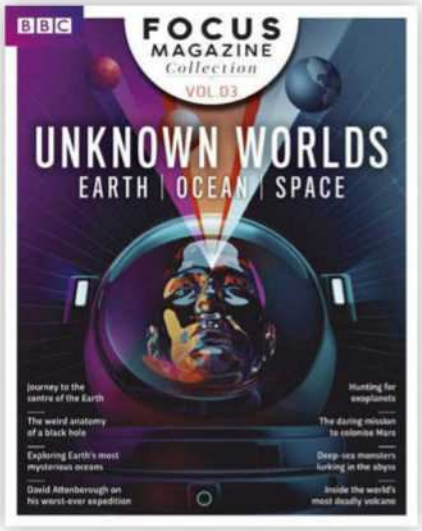

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ALEX FRANKLIN-CHEUNG
Environment/ climate expert


DR PETER J BENTLEY
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PROF ALICE GREGORY
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DR CHRISTIAN JARRETT
Neuroscientist, science writer


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Biologist, geneticist


PROF ROBERT MATTHEWS
Physicist, science writer

YOUR QUESTIONS ANSWERED

APRIL 2018 | EDITED BY JAMES LLOYD

Why do tattoos fade?

ANTONIO JONES, LONDON

Tattoo needles deposit ink beneath the epidermis. This is deep enough that the ink won't be immediately shed with the skin cells of the upper layers, but macrophage cells from your immune system will gradually absorb the ink and disperse it. And the UV frequencies in sunlight are energetic enough to break down the ink molecules over time, so tattoos that are always exposed – such as on the fingers or face – fade quicker than those covered by clothing. LV

Women from the Chin tribe of Myanmar were tattooed as young girls, to protect them from invaders. The practice is no longer allowed, so these tattoos are only seen on the older generation

PHOTO: GETTY

Why have big cats evolved but not big dogs?

JONNY THOMPSON, GLASGOW

Big cats mostly hunt alone and rely on a short burst of speed to catch their prey, and swipes from their claws to bring it down. Wild dogs hunt differently, using teamwork to chase prey over long distances until it collapses from exhaustion. A larger body is a liability in this sort of endurance contest – it requires more energy to haul around and doesn't improve the chances of a kill. We colloquially group cats and dogs together because we keep domestic versions of both of them as pets, but they are different animals that have evolved to fit different niches. Cats and dogs are both in the Carnivora order, but their last common ancestor lived about 42 million years ago. Since then they have diverged into feliforms (cats, hyenas and mongooses) and caniforms – a more diverse group that includes raccoons and walruses, as well as dogs. Bears are caniforms too, and are more closely related to dogs than cats are. So you could argue that big dogs do exist, and the equivalent of the tiger in the dog world is a grizzly bear! **LV**

Can you develop dyslexia as an adult?

LAURA TRENCHER, NEWCASTLE

Yes. Sometimes this is just childhood dyslexia that isn't diagnosed until much later. But it is also possible to develop the same symptoms as a result of brain injury or dementia. In fact, a 2012 study at the University of Dundee concluded that the normal process of ageing tends to make us mildly dyslexic as we get older. **LV**

Is it possible to have the flu and a cold at the same time?

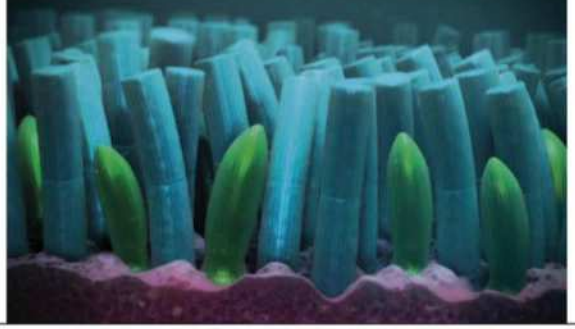
ERIN BEACH, INVERNESS

Flu and common colds are caused by different families of viruses, so it's possible to have both in your body at the same time. But a lot of your immune response to one virus also makes conditions inhospitable for any other virus, so it is less likely that a second infection will take hold while you are fighting the first. This so-called antiviral state doesn't protect you against bacterial infections though. A lot of the deaths from flu are actually due to secondary bacterial pneumonia infections that can take hold while your immune system is busy fighting the flu. **LV**

Why can you see faint stars better if you don't look directly at them?

LEAH VICTORIA SMITH, HEREFORD

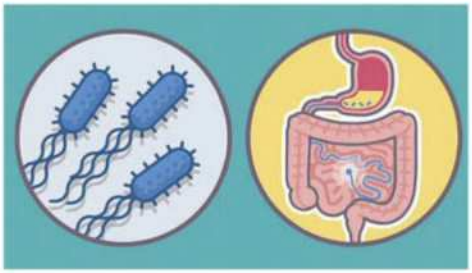
Astronomers call the technique 'averted vision', and it exploits the fact that our eyes contain two types of light-detecting cells. Around the centre of the retina are so-called cone cells, which give us colour vision and need good light levels. Away from the centre are rod cells, which are responsible for black-and-white vision, and work better than the cone cells at low light levels. Looking off to one side allows more light from faint objects to strike the rod cells, and become visible to us. RM



PHOTOS: GETTY X4, SCIENCE PHOTO LIBRARY ILLUSTRATIONS: RAJA LOCKEY

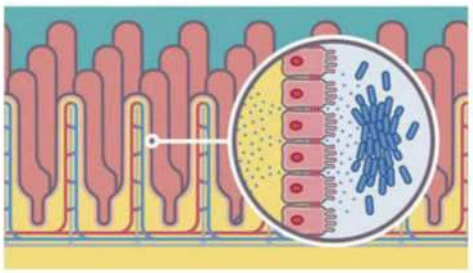
...I GET FOOD POISONING?

Most of us are all too familiar with the unpleasant symptoms of food poisoning, from vomiting to diarrhoea and debilitating stomach cramps. Although viruses play a role, bacteria are common offenders, with *Salmonella* and *Campylobacter* topping the poisoning charts. Some bacteria wreak havoc by multiplying in the body before delivering their toxins, which spark an immune reaction in the gut. Others, such as *Staphylococcus aureus*, poison us by contaminating food with toxins.



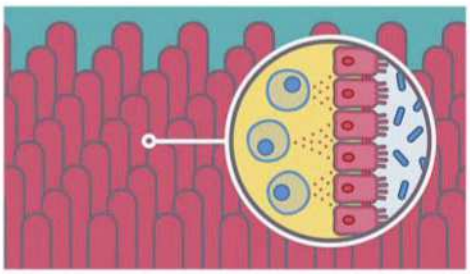
1. Bacteria enter

Some bacteria or enterotoxins (intestinal toxins) can survive harsh stomach conditions, making their way to the gut. There, the misery begins, sometimes up to 72 hours after eating the offending meal.



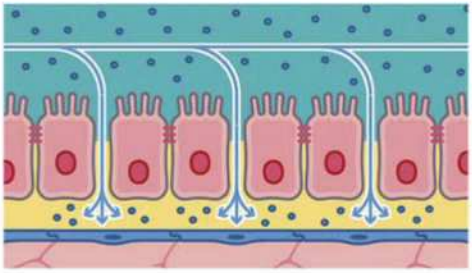
2. Bacteria multiply

Undetected by the body's immune system, the bacteria quietly multiply, producing toxins. These invade and penetrate the gut lining, setting off a strong immune response.



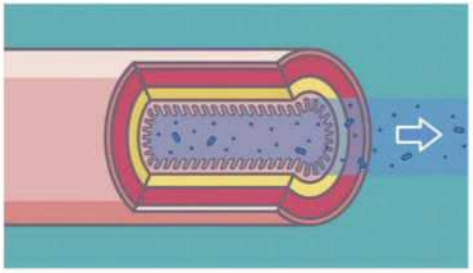
3. Immune response

Immune cells release signalling proteins called pro-inflammatory cytokines, which set in motion a series of steps causing gut inflammation and swelling, leading to discomfort.



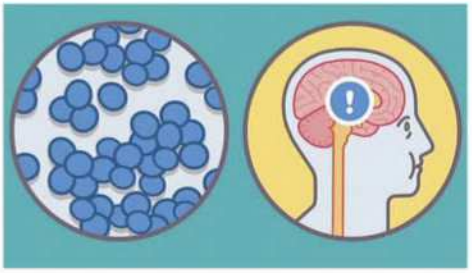
4. Flooded intestines

The intestinal wall is designed to absorb nutrients and water from food. Bacterial toxins can cause pores to open in the wall, allowing water and other molecules to flood in.



5. Diarrhoea and dehydration

The excess fluid and electrolytes in the gut lead to watery diarrhoea, which has a beneficial role of flushing out the bacteria and their toxins. It can, however, cause dehydration.



6. Vomiting

Some bacteria don't cause vomiting, but *Staphylococcus aureus* enterotoxins do. Research suggests that they may stimulate the vagus nerve which transmits a signal to the brain's vomiting centre.

IN NUMBERS

256,000

Estimated number of premature deaths in the USA caused annually by childhood exposure to lead.

15

The number of newly confirmed exoplanets detected orbiting red dwarf stars close to Earth by NASA's Kepler spacecraft.

Are there any materials that don't expand when heated?

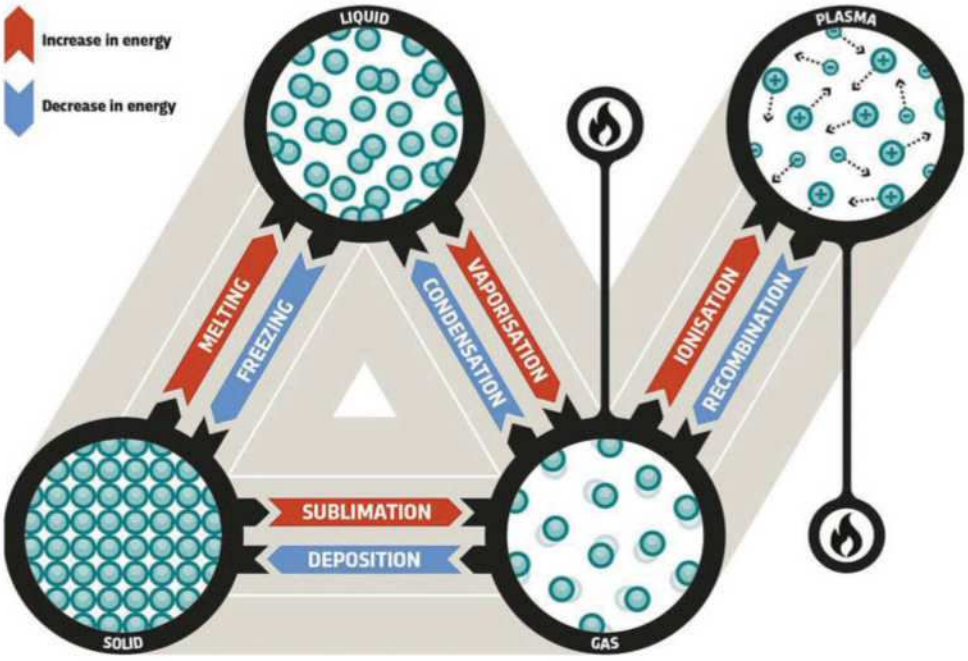
S BHAT, HOWRAH, INDIA

Polymers like rubber shrink on heating as their molecular chains curl up, and water shrinks when warmed from its freezing point to around 4°C. After that, though, it behaves normally, and expands on warming. In contrast, so-called negative thermal expansion (NTE) materials never behave themselves. Discovered in 1959, they include zirconium tungstate, whose bizarre crystal structure means that it keeps shrinking as it's warmed from any temperature above absolute zero (-273°C) to over 770°C. RM

What state of matter is fire: solid, liquid or gas?

TOBY GRAHAM, SHREWSBURY

The nature of a flame depends on what is being burnt. A candle flame will primarily be a mixture of hot gases (air and vaporised paraffin wax). The oxygen in the air reacts with the paraffin to produce heat, light and carbon dioxide. Other materials – such as magnesium – burn much hotter, resulting in the fourth state of matter: plasma. **ML**



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Does milk really build healthy bones?

CHRISTINE BRESSAT, WEST SUSSEX

The body needs a regular intake of calcium for a range of needs, not least building and maintaining bones. If it doesn't get enough calcium from the diet, it will extract it from bones. Although some disagree on the importance of dairy products, they are undeniably good sources of absorbable calcium. Healthy bones also require vitamin D and potassium. It's a good idea to boost calcium levels by eating plenty of leafy vegetables, beans and seeds. **ED**

Do other animals get allergies?

SACHIN PATEL, MILTON KEYNES

Yes. Cats, dogs and horses can all develop allergies in much the same way that humans do. There are three main kinds of allergy in animals – food, flea bites and environmental allergies such as grass pollen and mould spores. Allergies seem to be much more common in domestic pets than in wild animals or farm animals that spend most of their time outdoors. This may be because the more hygienic conditions in human houses leave less work for the immune system and so it gets inappropriately sensitised to normally harmless particles in the environment. Animals typically get more allergic as they get older. **LV**

PHOTOS: GETTY X3, FLPA ILLUSTRATION: RAJA LOCKEY

Animals with flea allergies will suffer from severe itching, and may even develop a form of dermatitis after being bitten

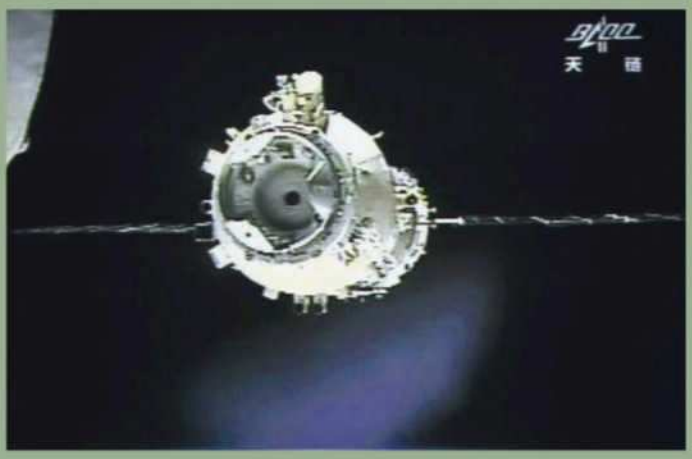
Why isn't the Earth perfectly spherical?

ANDREW KEMP, CHESHIRE

The Earth's rotation creates an outward force perpendicular to its rotation axis which, crucially, is proportional to the distance from that axis. Hence, the highest force is felt at the Earth's equator, while the force is zero at the poles. Since the Earth is not perfectly solid throughout, this force results in the Earth being 'squashed' into a slightly flattened sphere. The effect is quite small. The diameter at the poles is about 12,714km and at the equator is about 12,756km; hence the amount of flattening (or 'oblateness') is only about 0.3 per cent. However, this equatorial bulge (42km) is about twice the distance from the top of Mount Everest to the deepest part of the ocean. **AGu**

If the Chinese space station Tiangong-1 lands in my backyard, do I own it?

TOM HAMPTON, TOWNSVILLE, AUSTRALIA



China lost control of Tiangong-1 in March 2016, so plans to deliberately de-orbit it were abandoned. Instead, its orbit is expected to decay around March 2018. Most of the station will burn up during atmospheric re-entry, but small pieces might reach Earth's surface – Australia is within the potential impact zone. Technically, spacecraft remain the property of the launching nation, but current international law is much more concerned with who is responsible for the damage and pollution at the crash site. When Skylab debris hit Australia in 1979, NASA allowed local residents to keep any pieces they found. **LV**

Q&A

WHO REALLY DISCOVERED?

HALLEY'S COMET

EDMOND HALLEY

CHINESE ASTRONOMERS

The most famous of all comets was certainly seen by the English astronomer and mathematician Edmond Halley when it flew round the Sun in 1682, but he did not discover it. The credit for that goes back at least another 2,000 years to 240 BC, when unknown Chinese astronomers noted what they called a 'broom star' appearing in the eastern sky in May of that year.

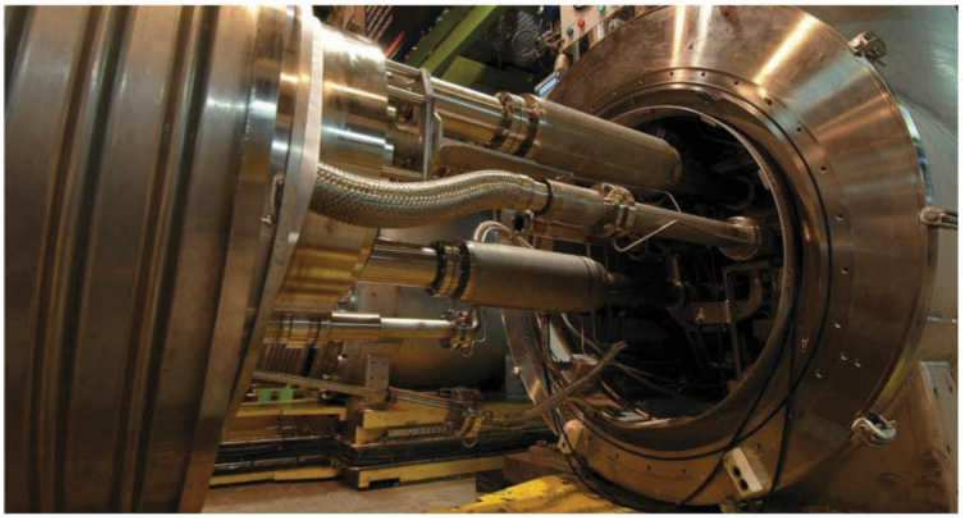
Halley's claim to the name stems from his crucial discovery about the nature of the eponymous object. While studying a list of comet observations over the centuries, he noticed that the years 1531, 1607 and 1682 all featured the appearance of one of these supposedly capricious portents of doom. Was it just a coincidence that they were all about 76 years apart? Using Newton's then newly published law of gravity, he showed that they were all the same object, swinging round the Sun on a vast orbit. Halley predicted it would return in 1758, which it duly did. While he didn't live to see it, his calculations played a key role in showing that supposedly fickle natural phenomena can be understood through the power of science. **RM**

Is there any reason why plastic bottles cannot be reused in the way glass ones were in the past?

GEOFF DUNWELL, MAIDENHEAD

Existing plastic bottles are designed for single use and aren't sturdy enough to withstand the wear and tear associated with collection, cleaning, refilling and reuse on a commercial scale. Reusable bottles need to be sterilised, which involves washing with very hot water and possibly chemical solutions to kill any bacteria.

But while glass is resistant to high temperatures and to many corrosive chemicals, most plastics are liable to melt, deform or sustain damage from these cleaning methods. Nonetheless, it might be possible to produce a reusable plastic bottle, but to the best of our knowledge no company has done this yet. **AFC**



What new insights has the Higgs boson given us?

ANDY FLETCHER, LONDON

The discovery of the Higgs boson in 2012 led to global headlines, and the award of Nobel Prizes to, among others, the British theorist Peter Higgs. He was one of a small group who argued that the particle was essential for explaining that most basic property of matter: mass. The Higgs is linked to an all-pervasive energy field that makes particles behave as if they have mass. Since its discovery, experiments at the Large Hadron Collider (LHC) at CERN have probed the properties of this bizarre particle. So unstable it's never been directly observed, the Higgs decays into other particles, and studying these could give new insights into the forces of nature.

According to current theories, the Higgs can decay into at least eight different pairs of particles. Yet the most common outcome – two so-called bottom quarks – has proved the hardest to confirm. That gave hope that something unexpected might be found. But the LHC team has recently announced they've detected the decay into bottom quarks – and it's right in line with the Standard Model (the theory that classifies elementary particles and describes three of the four known fundamental forces). Physicists are far from delighted, however. They were hoping to get glimpses of radical new phenomena, but as yet nothing has turned up. **RM**

PHOTOS: GETTY X5 ILLUSTRATION: RAJA LOCKEY

WHAT IS THIS?

Dust cascades
The Mars Reconnaissance Orbiter snapped this image of the Red Planet earlier this year. The darker coloured streaks are caused by dust cascading down the planet's slopes. The cause of these avalanches is not known, but it is thought that it could be due to sudden warming of the planet's surface, perhaps due to seasonal changes. As more dust settles from the sky, the streaks slowly fade away.

WHAT'S IN...

...LAUNDRY PODS?

Those pretty little pods are packed full of compounds that work together to remove all sorts of grime and grease from your clothes. These chemicals are at much higher concentrations than in liquid detergents. And at these high concentrations their contents are very alkaline, which means they can cause chemical burns. So don't eat them!

Why do we rub our faces when we're tired?

ALISON SHIELDS, BUCKINGHAMSHIRE

Often when we are tired, our eyes feel itchy and rubbing them stimulates the tear ducts to release lubricating fluid. But there is also a weird connection between the ophthalmic nerve that serves the face, scalp and eyes, and the vagus nerve that runs to the heart. Rubbing your face or pressing your eyes triggers the 'oculocardiac reflex', which lowers the heart rate. This can help you relax when you are tired or stressed. **LV**

How did the Romans do arithmetic with their numerals?

KATHLEEN HUGHES, NEW YORK, US

Despite our extensive knowledge of the Romans and their works, little is known about how they performed even basic arithmetic using their notoriously unwieldy numerals, where a two-digit number like 78 becomes the seven-letter horror LXXVIII. Clearly, Roman labourers wanting to work out, say, the area of a floor measuring 78 by 37 paces would take ages to establish it's MMDCCCLXXXVI square paces. Or would they? Research by cognitive scientists has shown that despite appearances, calculations with Roman numerals can be broken down into steps needing relatively few intermediate results to be remembered. With practice and the use of an abacus, such rules might explain how the Romans coped with the sums needed to build and maintain an empire. RM

PHOTOS: GETTY X2

For electric cars charged from the mains, what is the CO_2 per mile?

JOHN WHITBREAD, STAFFORDSHIRE

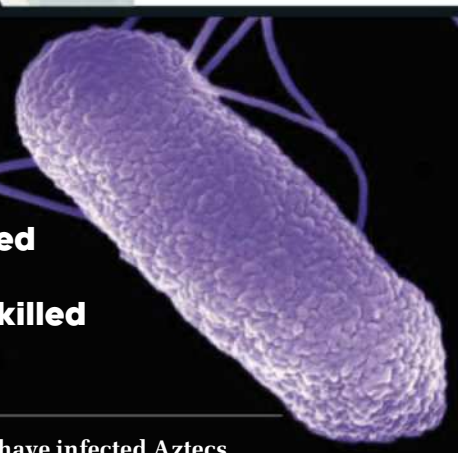
There are many variables to consider. Roughly speaking, in the UK, an electric car charged from the mains currently emits roughly 80g of CO_2 per mile, compared to 216g CO_2 per mile for the average petrol car. An electric car's emissions depend on what proportion of its electricity is derived from burning fossil fuels, and therefore varies from country to country, and according to the time of day. As we generate more energy from renewable sources, the carbon emissions of electric cars will drop further. **AFC**

Does a crashed electric vehicle pose a fire or electrocution risk?

ALAN THOMAS, VIA EMAIL

Despite their green image, lithium batteries can turn pretty nasty if damaged. In electric vehicles, they are surrounded by coolant. If that leaks out, the batteries can heat up and catch fire. They also contain electric charge, and emergency service personnel have to avoid touching or cutting into the high-voltage units as the consequences can be deadly. Vehicle designers have worked hard to reduce the fire and electrocution risks, but they've not eliminated them. **RM**

QUESTION OF THE MONTH



Salmonella enterica **is a rod-shaped bacterium that can be carried without symptoms**

I recently read that 95 per cent of the Aztecs were killed by European diseases. So why weren't Europeans killed by Aztec diseases?

GEOFF DUNWELL, MAIDENHEAD

Debate has long raged over what caused the epidemics that wiped out large sections of Aztec society after Europeans arrived in the 16th Century. The most devastating epidemics – called cocoliztli – have been blamed variously on measles, smallpox and typhus.

Recent analysis of DNA from the teeth of people buried during a cocoliztli suggests that *Salmonella enterica* may have been partly to blame. It is possible to carry salmonella without falling ill, so healthy Spaniards could feasibly have infected Aztecs lacking resistance.

Some suggest that Europeans had some natural disease protection after a long history of living in close quarters with domesticated animals and their waste. The Aztecs had few domesticated animals, depending heavily on corn in their diet, which was supplemented with insects, fish and some wild game. They also had more hygienic living conditions than many Europeans, with a system of aqueducts bringing in fresh water. **ED**

WINNER!

Geoff Dunwell wins a Kreafunk aGlow speaker, (£99, **prezzybox.com**). This outdoor light-up speaker is perfect for camping and garden parties, offering 20 hours of playback, a dimmer switch, a mic for calls and Bluetooth functionality.

NEXT ISSUE:

How do scientists weigh planets?

Do birds wee?

Are there stars between galaxies?

Email your questions to **questions@sciencefocus.com** or submit online at **sciencefocus.com/qanda**

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

APRIL 2018 | EDITED BY HELEN GLENNY

01

FAKE
SCIENCE GALLERY DUBLIN
2 MARCH – 3 JUNE 2018

FAKE IT

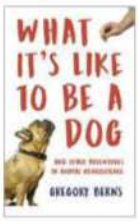
Look closely. Are these scientific specimens real, or fake? How do you know? Heather Beardsley has installed 'fabulatory' samples alongside the real deal in an exhibition called *FAKE* at the Dublin Science Gallery, because she wants us to reassess everything we usually take for granted within the walls of a museum. While you're there, check out the robofrogs that can attract real female mates, commission your own algorithmic musical recording, and remix your polite fake laugh into something that sounds convincing.

FAKE's mission is to transform the image of the inauthentic. You'll investigate genetically modified stingray-leather shoes, taste lab-created flavours, and decide what 'fakery' is acceptable to you. After all, if it does the job, who cares?

LEARN MORE

On 2 May, Science Gallery Dublin will also be hosting the talk *Scientific B*llsh*t: How To Smell A [Lab] Rat* to help you learn how to spot scientific fake news for yourself.

02



WHAT IT'S LIKE TO BE A DOG
BY GREGORY BERNS
OUT 12 APRIL (£16.99, ONEWORLD)

READ YOUR DOG'S MIND

When neuroscientist GREGORY BERNS saw military dogs jumping from helicopters, he thought that maybe pooches could be trained to go into MRI scanners too

PHOTO: GREGORY BURNS

Most neuroscientists study humans. Why did you start looking at dogs?
After 20 years of working with humans, I had this crazy idea. I wanted to know about the dog-human relationship. Do they love us in the way we love them? Or is it all a sham, an innocent duplicity propagated by dogs to act all cute in exchange for food and shelter?

How did you get started?
Everyone thought I was crazy, but I teamed up with a local dog trainer and taught Callie, my black terrier mix, to go into an MRI scanner unrestrained, completely awake, so I could see what she was thinking. We then recruited other volunteers and ended up with a dozen dogs who were trained to sit still in MRIs.

You called them volunteers?
We followed three rules. We didn't do anything to harm the dogs, we didn't restrain them at all, and we gave them the right of self-determination. We provided steps for them to walk in and out of the scanner instead of placing them in. The dogs had the same fundamental privilege as humans participating in research: the right to refuse.

So, what is it like to be a dog?
Our most important finding was how different the dogs are from each other. Implicit in our question 'What is it like to be a dog?' is the assumption that all dogs are the same. But that's ridiculous! That's like asking what it's like to be human. Like humans, dogs are individuals, and no matter what experiment we do, there's always a range of brain activity patterns that correspond to their personalities.

What were your most important findings?
We've done over a dozen different experiments. In one, we found that dogs have a part of their brain that recognises faces, just like primates and humans. We don't know whether that's hardwired or a learned response from living with humans, but we now know that they pay attention to our faces.

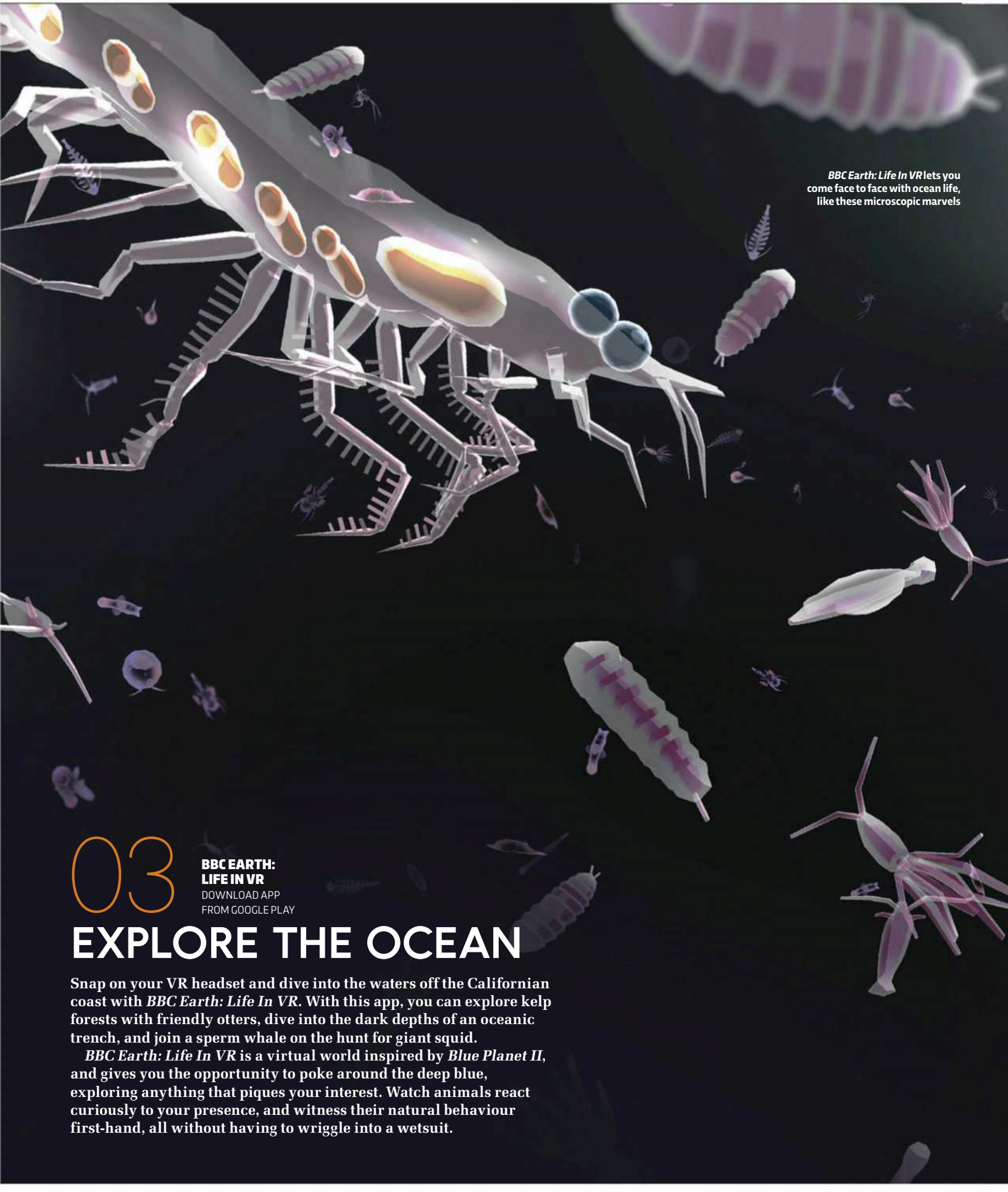
In another, we looked at how dogs process the smells of members of their household, and we found that a dog's reward system is most responsive to the smell of their owner, indicating that the smell has a positive association for them.

Is that positive association because they love us, or are they just using us for food?
We did an experiment where one hand signal meant that they'd get a treat, and another meant that their owner would pop in to view and praise them. We found that those reward systems were equally active. The experiment showed that praise itself is rewarding to the dog too. It's not just all about food.

We can't say exactly what that feels like for the dogs, but we know that when we give them things that they like, such as food or praise, we see a reward system response that's similar to what we see in humans. From that, I concluded that it's highly likely that the dogs are feeling something similar to how we feel when we're given something we like.

As dog owners, what do we need to know?
We often anthropomorphise too much – dogs aren't miniature humans. They may understand some things but they don't have the real estate in the brain to process language like we do. So, practically, less is more when we're speaking to our animals. Fewer words is better, and consistency is critical.

But they do have basic emotions like we do. They experience negative ones like fear and anxiety, but they also enjoy things and experience pleasure, too.



BBC Earth: Life In VR lets you come face to face with ocean life, like these microscopic marvels

03

BBC EARTH: LIFE IN VR
DOWNLOAD APP FROM GOOGLE PLAY

EXPLORE THE OCEAN

Snap on your VR headset and dive into the waters off the Californian coast with *BBC Earth: Life In VR*. With this app, you can explore kelp forests with friendly otters, dive into the dark depths of an oceanic trench, and join a sperm whale on the hunt for giant squid.

***BBC Earth: Life In VR* is a virtual world inspired by *Blue Planet II*, and gives you the opportunity to poke around the deep blue, exploring anything that piques your interest. Watch animals react curiously to your presence, and witness their natural behaviour first-hand, all without having to wriggle into a wetsuit.**

04

SENSATIONAL BUTTERFLIES
NATURAL HISTORY MUSEUM, LONDON
29 MARCH – 16 SEPTEMBER

SAY HELLO TO THESE SENSATIONAL BUTTERFLIES

The Butterfly House at London's Natural History Museum has over 100 species for you to track down in its annual immersive exhibit, now in its 10th year. Keep an eye out for these six, picked by senior curator DR BLANCA HUERTAS for their fascinating colours

MALACHITE (*Siproeta stelenes*)
Malachites begin their lives as black caterpillars with terrifying-looking red horns. However, the adults are bright green in colour, which is quite unusual among butterflies. The brown border on their wings comes from melanin, the same chemical that gives human skin its colour.

AFRICAN SWALLOWTAIL (*Papilio dardanus*)
Because of its genetic complexity, the African swallowtail has been branded as 'the most interesting butterfly in the world' by scientists. The males are bright yellow, but the females' wings have more than 14 variations. Their wings may even mimic the shapes and patterns of poisonous butterfly species, to deter predators from nibbling on them.

POSTMAN (*Heliconius erato*)
From the southern US to northern Argentina, you'll find postman butterflies, along with the many other species in their genus. Postman butterflies copy the wing patterns of inedible butterflies to deter predators, and their bright red markings allow them to identify each other when they're searching for a mate. These butterflies have a rather macabre start to life too – postman caterpillars are highly cannibalistic.

PHOTOS: GETTY X3, ALAMY X2, NATURAL HISTORY MUSEUM

OWL (*Caligo atreus*)

Owl butterflies are one of South America's biggest, with wingspans of up to 20cm. They get their name from their large spots, which resemble an owl's eyes. It's not known exactly what those spots are for, although scientists believe they might trick a predator into thinking that it's staring at a much larger animal. During flight, and when they rest in the sunshine to get warm, male owl butterflies glimmer with different shades of metallic indigo, blue and yellow – a trick they use to attract a mate.

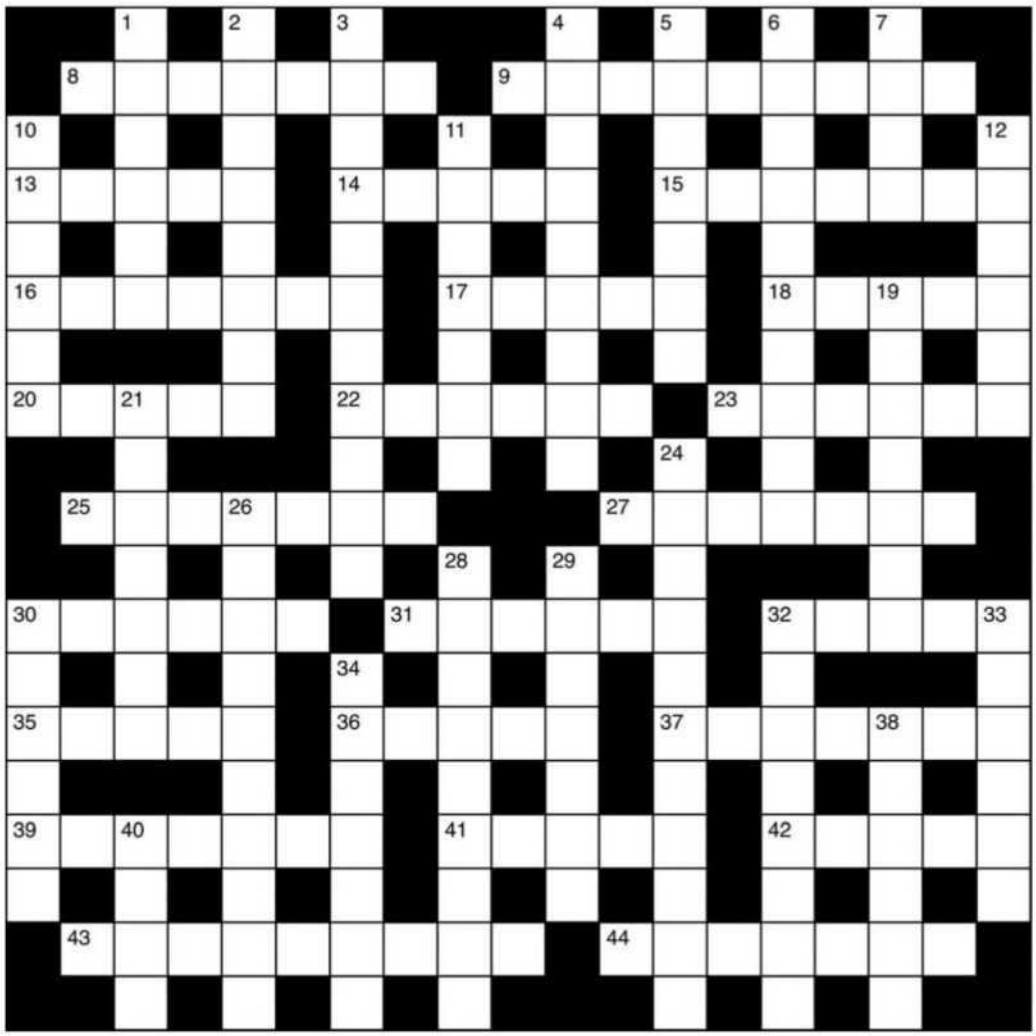
BLUE MORPHO (*Morpho helenor*)

Like the vast majority of butterflies, the blue morpho's wings are covered in tiny scales. The morpho's iridescent colouration stems from multiple thin layers in the scale ridges, which affect the diffraction of the light. When the blue morpho is in flight, the colours look even more intense. And it's not just the butterflies that are impressive – blue morpho caterpillars are covered in colourful patterns and tufts of fur.

MONARCH BUTTERFLY (*Danaus plexippus*)

You'll find monarchs on every continent except Antarctica, but it's the North American variety that interests scientists the most. Each autumn, monarchs from the colder parts of the US and Canada migrate to Mexico and California where they will overwinter until March. Then, over the course of four to five generations, the butterflies will travel back to northern climes for the summer. When autumn rolls around again, the latest generation will migrate back to the overwintering grounds. Their orange colour isn't just for decoration – it warns predators they're poisonous, thanks to the cyanide they accumulate in their bodies from the plants they eat as caterpillars.

BBC FOCUS CROSSWORD
GIVE YOUR BRAIN A WORKOUT



ACROSS

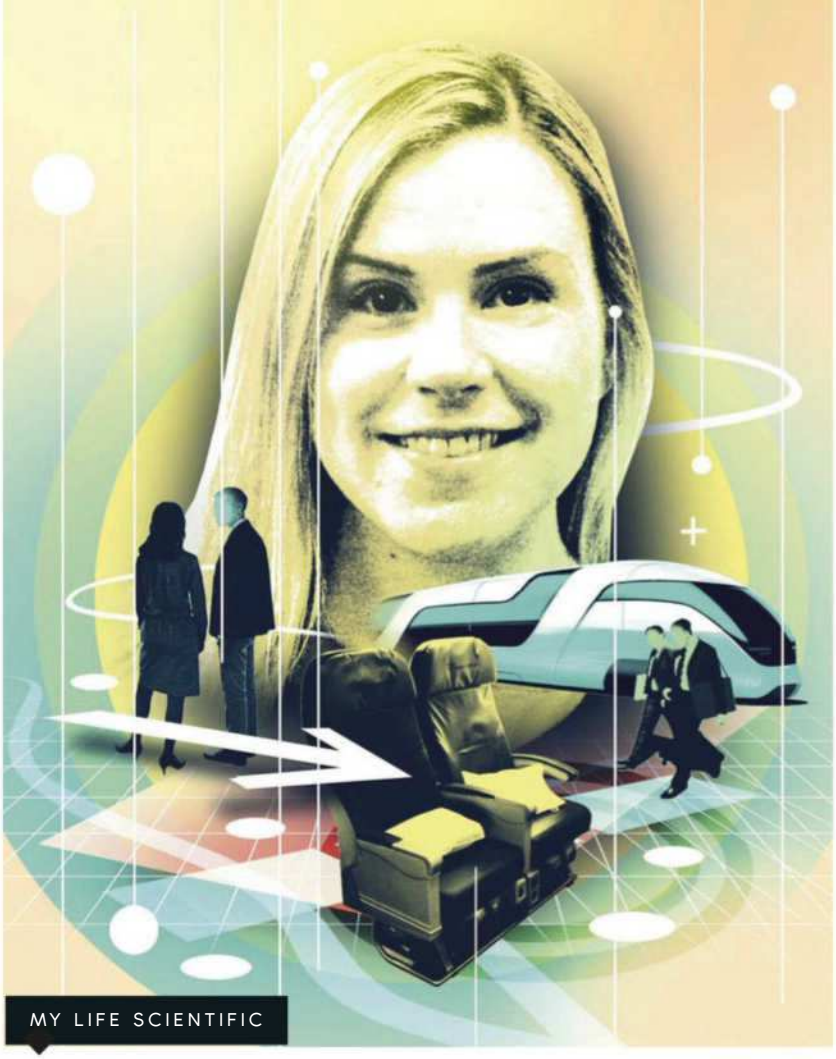
8 Heard talk of pie filling (7)
9 Vegetable when father gets sugar back (9)
13 Small, feeble track (5)
14 Molten rock gets registered as immature form (5)
15 Writer has neat cocktail with a bit of petrol (7)
16 Constituent that provides heat (7)
17 Graduate returns equipment for use of wax (5)
18 The Simpsons' resident poet (5)
20 Poison can contain bull (5)
22 Compete with yours truly to get flower cluster (6)
23 A professor is a handsome youngster (6)
25 Weirder than artist getting unknown disease (7)
27 Californian giant joins socialist club (7)
30 Account concerning wine (6)
31 Knock favourite part of machine (6)
32 Transport nothing with British chocolate substitute (5)
35 Enemy has ship to ditch (5)
36 Flavouring is an alternative additive (5)
37 I have gone off American type of rock (7)
39 Encourage chief to be a boffin (7)
41 SF writer's holy novel reaches the end (5)
42 A riot out of proportion (5)
43 Status bar worked at lower levels (9)
44 Invention of a type of fiction (7)

DOWN

1 Church city has a decorative finish (6)
2 A beer den wasted in the city (8)
3 Workers get expert to allow song on time (11)
4 A matching bit within artificial sweetener (9)
5 Fish and grape recipe captivates one king (7)
6 Managed to get island outline in dry area (4,6)
7 Gold gives artist quality (4)
10 Incline towards a perfume (6)
11 A bar sent CIA out for coffee (7)
12 Sympathy towards second suit (6)
19 Human problem, getting round right to some work (3-4)
21 Frog gets cross, having space to work (7)
24 Particle net adjusted, moving to the middle (11)
26 Antelope played three beats (10)
28 Rebuild a chapel – it shows Islamic realm (9)
29 Kiwi finds suitable coordinates with hesitation (7)
30 Engineers gets wire in an instinctive move (6)
32 Sorry prisoner got banal (8)
33 Boots worn by new terrier (6)
34 Race lad around crater (7)
38 Angle that's hard to understand (6)
40 Impudence overheard in France, formerly (4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW** Please be aware the website address is case-sensitive.



MY LIFE SCIENTIFIC

Aoife Hunt

This month, mathematician **Aoife Hunt** talks to **Helen Pilcher** about the best plane seat, the best train seat, and how maths can help keep people moving

Aoife goes back to Ireland every year for the Cork City Marathon. She completes it in relay with her family, fuelled by pints of Guinness the night before.

What do you do?
I study the way that people move around in stadiums, museums, hospitals and the like. I collect data, then use it to see how the building will perform. Will it hold enough people? Will they be able to use the space effectively? Will they be able to get out in an emergency?

What projects have you worked on?
Wembley Stadium, St James's Park and Principality Stadium. I once spent a week timing how long it took people to use the toilets in Ottawa airport. Rock 'n' roll! We've done stuff for Glastonbury Festival too.

Can you explain why, at festivals, there is always a queue for the toilets?
I can tell you why there shouldn't be. Before the event, we look at the site design, model how people are likely to move, then help make decisions about how things should be organised. During the festival, we have someone on site who makes adjustments as things unfold. You can change routings or set up temporary queuing systems to keep things moving.

What happens in an emergency?
Despite what the media suggests, it's been shown that people don't tend to panic in emergencies. This is important because it means we can predict what is likely to happen. People follow the crowd and leave via familiar routes. We can give people better, more timely information and build designs that work with, rather than against, our natural behaviour.

What's the safest seat on a plane?
You're most likely to survive a crash if you sit within five rows of an exit. Remember – the vast majority of incidents have survivors, so pay attention to those safety demos.

What's the best seat to sit in on a train?
B29. This has nothing to do with my work, just personal preference. It's backward-facing so more likely to be free. It has a table and a socket. It's far enough from the toilets so that it doesn't smell, but close enough in case you need to go. Does that make me sound a bit 'Sheldon from *The Big Bang Theory*'? Of course, now people know about this, it's more likely to be taken.

Sorry about that. If you weren't a mathematician what would you be?
I'd work for ESA. I'd do anything. I'd make tea there. There's nothing like stargazing for putting life in perspective. I think if stressed city workers spent three minutes a day looking through a telescope it would improve their wellbeing.

Of what are you most proud?
A couple of years ago, I became the first woman to win the Society of Fire Protection Engineers Scholar Award in recognition of the work I did on evacuating hospitals. It turned out no one had ever modelled that before. Unbelievable! It was a real honour.

I heard that you almost replaced Carol Vorderman on *Countdown*...
I did audition, but Rachel Riley beat me. I still do a lot of outreach. Women are massively under-represented in maths. We need to do something about it because we're missing out on talent. I'd like to encourage women mathematicians to get out there and show people what they do.

Aoife Hunt is associate director at Movement Strategies
movementstrategies.com

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